PATENT
Docket No. 110.01760101

IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

Applicant(s):	IWASAKI	)	Group Art Unit:	1724
		)		
Serial No.:	10/081,176	)	Examiner:	T. M. Lithgow
Confirmation No.: 2734		)		
		)		
Filed:	February 22, 2002	)		
		)		
For:	SEPARATION APPARATUS AND METHODS			

DECLARATION UNDER 37 C.F.R. §1.132

Mail Stop Amendment
Commissioner for Patents
P.O. Box 1450
Alexandria, VA 22313

Dear Sir:

I, Iwao Iwasaki, declare and say as follows:

1. I received a doctor of science degree in metallurgy from MIT (1957), a Doctor of Engineering degree from Tohoku University, Sendai, Japan (1962), and have been elected to the National Academy of Engineering for my decades of work performing research, including research with regard to the processing of iron ore. I received an honorary doctor of engineering degree from Colorado School of Mines (2001). I have been the Endowed Taconite Chair at the Natural Resources Research Institute (NRRI), University of Minnesota Duluth, since June 1999.

2. I am a coauthor with Chuying Wu of the accompanying Exhibit A (Iwasaki et al., "Magnetic Field application in hydroseparators and flotation cells," Progress Report No. 1, Coleraine Minerals Research Laboratory, Natural Resources Research Institute, Univ. of Minnesota-Duluth, CMRL/TR-0012,NRRI/TR-2000/38, 2001 Aug. 10 (released to public 27 Feb. 2002); 22 pgs.)

3. I am a coauthor with Salih Ersayin of the accompanying Exhibit B (Iwasaki et al., "Effect of Magnetizing/ Demagnetizing on Cationic Silica Flotation Under a Magnetic Field," Final Report, Coleraine Minerals Research Laboratory, Natural Resources Research Institute, Univ. of Minnesota-Duluth, CMRL/TR-01-20, NRRI/TR-2002/04, 2001 Oct. 17 (released to public 27 Feb. 2002); 8 pgs.); Exhibit C (Iwasaki et al., "Magnetic Field Application in Cationic Silica Flotation," Final Report, Coleraine Minerals Research Laboratory, Natural Resources Research Institute, Univ. of Minnesota-Duluth, CMRL/TR-01-04, NRRI/TR-2001/14, 2001 May 4 (released to public 27 Feb. 2002); 1-39.); Exhibit D (Ersayin et al., "Magnetic field application in cationic silica flotation of magnetic taconite concentrates," *Minerals and Metallurgical Processing*, 2002 August; *19*(3):148-153); and Exhibit E (Iwasaki et al., "Magnetic Field Application in Cationic Silica Flotation," Final Report, Coleraine Minerals Research Laboratory, Natural Resources Research Institute, Univ. of Minnesota-Duluth, CMRL/TR-01-04, NRRI/TR-2001/14, 2001 May 4 (released to public 27 Feb. 2002), 1-39).

4. I have read and am familiar with the Office Action mailed 5 January 2005 with respect to the above-identified U.S. Patent Application No. 10/081,176 filed 22 February 2002. The Office Action cites the documents in Exhibits A-E in a rejection of pending claims under 35 U.S.C. 102(f) indicating that "applicant Iwasaki may not be the sole inventor" as Exhibits A-E are "coauthored by the applicant and one of either Salih Ersayin or Chuying Wu."

5. Chuying Wu was a Program Director at the Coleraine Minerals Research Laboratory of NRRI at which I am the Endowed Taconite Chair. Under my direction, Chuying Wu only assisted in configuring a test set-up used to test the claimed invention. The test set-up is described in Exhibit A. Chuying Wu did not contribute to any of the pending claims in the present application.

6. Salih Ersayin was a Program Director of Concentrator Modeling and Simulation at the Coleraine Minerals Research Laboratory of NRRI at which I am the Endowed Taconite Chair. Under my direction, Salih Ersayin merely assisted me in testing the claimed invention in

a pilot plant set-up. Such tests are described in Exhibits B-E. Salih Ersayin did not contribute to any of the pending claims in the present application.

7. I am the sole inventor of the claimed subject matter of the above-identified U.S. Patent Application No. 10/081,176 that is commonly disclosed in Exhibits A-E. The other co-authors, Salih Ersayin and Chuying Wu, of Exhibits A-E did not directly participate in the subject matter claimed as set forth above.

8. I further declare that statements made herein of our knowledge are true, and that all statements made on information and belief are believed to be true; and further that these statements were made with the knowledge that willful false statements and the like so made are punishable by fine or imprisonment, or both, under Section 1001 of Title 18 of the United States Code, and that such willful false statements may jeopardize the validity of the application or any patent issued thereon.

April 5, 2005
Date

Iwao Iwasaki
Iwao Iwasaki

Exhibit A

Progress Report No. 1

MAGNETIC FIELD APPLICATION IN HYDROSEPARATORS AND FLOTATION CELLS

COLERAINE MINERALS RESEARCH LABORATORY

August 10, 2000

By [signature]
Iwao Iwasaki
Senior Research Associate
Endowed Taconite Chair

By [signature]
Chuying Wu
Program Director

Approved by [signature]
Ronald L. Wiegel, Director
Coleraine Minerals Research Laboratory

CONFIDENTIAL

CMRL/TR-00-12
NRRI/TR-2000/38
Project #5698106

University of Minnesota – Duluth
Natural Resources Research Institute
5013 Miller Trunk Highway
Duluth, Minnesota 55811

Progress Report No. 1
Magnetic Field Application in Hydroseparators and Flotation Cells

Abstract: A magnetic gridwork was shown to be effective in controlling the iron losses in a laboratory hydroseparator and in laboratory cationic flotation in processing magnetic taconite concentrates. Its design and some preliminary test results are reported. The device is simple in construction, low-cost and may be installed readily in existing equipment. Pilot-scale testing is recommended to collect scale-up information needed for plant trials.

INTRODUCTION

In the cationic silica flotation of magnetic taconite concentrates, iron losses are high due to simultaneous flotation of fine, high-grade magnetite along with coarse middlings locked with magnetite. Much interest has been expressed by the iron ore industry in developing a means of minimizing the flotation of fine, high-grade magnetite.

The use of magnetic field in arresting flotation of fine magnetite has been tested successfully at the MRRC (1991) in laboratory scale, and at the CMRL (1995) in pilot scale, but plant trials of placing magnetic sheets in mechanical flotation cells experienced operational difficulties and tests had to be discontinued.

A magnetic gridwork design (a patent disclosure filed with the University Patent Office) indicated marked advantages in increasing the water rates in a laboratory hydroseparator, thereby allowing more efficient desliming. The same device was shown to prevent the losses of fine, high-grade magnetite particles to the froth in cationic silica flotation. The device is simple in construction, low-cost and may be installed readily in existing equipment, including hydroseparators and flotation cells.

Certain layered clay-type silicate minerals commonly present in magnetic taconite, such as minnesotaite, stilpnomelane and greenalite, adsorb excessive amounts of amine collectors by cationic exchange reaction, which may be responsible for the adverse effect on flotation results. In addition, the presence of the layered clay-type minerals in slime fractions with adsorbed collectors appears to be responsible for forming persistent flotation froths. Thorough desliming ahead of flotation in a hydroseparator using this device will cut down the amount of slimes in flotation and, hence, the reagent dosage, thereby alleviating the overly stable froth problem observed in certain plants.

Furthermore, the use of the device in flotation cells will not only help prevent excessive losses of iron units in the form of fine, high-grade magnetite, but is also expected to improve balling by keeping more fines in the final concentrates.

In this report, characteristic features of the gridwork design are described, and the results of a few preliminary tests with a laboratory hydroseparator and a Denver laboratory flotation cell are reported.

THE USE OF MAGNETIC FIELD IN IRON ORE PROCESSING

The use of magnetic field in a hydroclassifier was reported by Roe (1953). By imposing a magnetic field near the top of a hindered settling classifier tube, he demonstrated that the loss of fine magnetite into overflow products could be controlled. Sonolikar et al. (1988) reported laboratory column flotation tests by applying magnetic field on copper ores for reducing the recovery of magnetic minerals (pyrrhotite and magnetite). The magnetic minerals were shown to be arrested in the magnetization zone, though only low aeration rates were found to achieve in low magnetics contents in the froths. Higher air flowrates disturbed the captured magnetic particles, thus allowing them to float into the froths.

Seetharama et al. (1991) carried out a series of tests applying magnetic fields to laboratory Denver and Wemco flotation cells. Several configurations of permanent magnets, both static and dynamic, have been investigated with promising results. Using a laboratory flotation cell converted into a continuous flotation unit, they showed that fine magnetite particles were effectively depressed and the selectivity of separation was markedly improved.

Wu et al. (1995) tested the use of an electromagnet coil on an 8-inch diameter flotation column. Encouraged by the preliminary test results, they extended the tests using permanent magnets around the flotation column and then in a 50-cu.ft. Wemco flotation cell. They found that iron recoveries increased with field intensities up to 100 gauss, and further increase did not improve the iron recovery significantly; permanent magnetic sheets can be used to generate a magnetic field as effectively as the field generated by an electromagnet; and a magnetic field needs to be applied to the pulp/froth interface and cover the entire flotation surface. In these tests, ½-inch thick magnetic sheets were placed parallel facing each other vertically and an aluminum frame held the sheets in place.

In laboratory-scale tests, whether with a hydroseparator or a flotation cell, the use of electromagnets is convenient in varying the field strengths at will. However, for commercial-scale equipment, the use of electromagnets will be impractical with respect to size, design and safety. In the Mineral Separation sub-aeration machine, a horizontal gridwork arrangement was placed in the cell compartment to break the pulp swirl by the impeller action. A similar arrangement of magnetic sheets would provide the magnetic field distributed evenly over the flotation surface and in the vertical direction as in the case of an electromagnet placed around a hydroseparator or a flotation column. The gridwork would be simple in design, easy to fabricate and easy to install. Hence an investigation was initiated in determining the field strengths as a function of grid opening size and widths of magnetic sheet strips in the gridwork.

MAGNETIC GRIDWORK DESIGN CHARACTERISTICS

The simplest of the regular patterns for gridwork would be either squares or hexagons. Initially, a square pattern was thought to be easier to construct and structurally stronger. Magnetic gridworks were fabricated from 1/32-inch thick steel sheet by cutting out square frames, either ¼ or ½-inch wide with 4, 5 or 6-inch openings in inside dimensions. A magnetic sheet, ¼-inch in thickness, was cut to ¼- or ½-inch wide strips and placed over the steel frame to construct magnetic gridworks.

Figure 1 shows a typical field strength distribution inside a 5-inch square frame consisting of ¼-inch strips. The field strengths at the center were at minimum, and the strengths increased with the number of layers. Figure 2 shows the field strengths as a function of the number of layers for ¼ and ½-inch strips with inside openings of 4, 5 and 6 inches. The figure shows that the field strengths increased linearly with increasing numbers of layers; the smaller the opening, the higher the field strengths; and the wider the magnetic strips, the stronger the field strengths. The field strengths of ½-inch strips with 6-inch openings virtually overlap the field strengths of ¼-inch strips with 4-inch openings.

Figure 3 shows the field strength distribution inside a hexagonal frame of ¼-inch strips with 5-inch openings. The field strength distribution remained essentially the same as square frames. Hence, further testing was done with square openings for ease of construction, particularly, for multi-opening patterns.

To investigate if the field strengths might be affected in a multi-opening gridwork, a nine opening square frame of ½-inch strips with 6-inch openings was constructed, and the field strengths at the centers of the middle, side and edge squares were measured as a function of the number of layers. The results are plotted in Figure 4. A comparison of this figure with Figure 2 indicates that the field strengths were about twice as high at the center of nine squares as those of single squares. Another point of note in the figure is that even though the field strengths of side and corner squares are somewhat lower than the center square, they are still notably higher than a single square of the same-sized opening.

Hence, nine square frame gridworks of ½-inch strips with 8-inch and 10-inch openings were constructed, and the field strengths at the centers of the middle squares were measured as a function of the number of layers. The results are plotted in Figure 5. In the figure, the field strengths of a single square with a 6-inch opening are included. The field strengths of a single square with a 6-inch opening are virtually coincident with those at the center of nine squares with 8-inch openings.

It becomes of interest to see how high a field strength may be achieved with a multi-opening gridwork beyond nine squares.

EFFECT OF MAGNETIC FIELD ON HYDROSEPARATOR OPERATION

Test setup

The use of magnetic field on a hydroseparator was tested by using a Plexiglas tube, 4 inches in inside diameter and 48 inches long, with a slurry feed from a conical sump of approximately 10-gallon capacity via a peristaltic pump to the bottom of the tube. The overflow was returned directly into the sump for recirculation. A schematic diagram of the laboratory hydroseparator setup is shown in Figure 6.

Magnetic field was applied approximately halfway down the tube with an electric coil housed in a rectangular box 24-inches square and 16-inches in height with an opening of 11-inches square. The coil was energized by a silicon rectifier power supply. The field strength inside the opening was determined and plotted in Figure 7(a), which shows essentially constant all the way across. Its distribution in the vertical direction was determined and shown in Figure 7(b). The field strengths halfway down the opening, where the field strength was maximum, were measured as a function of energizing current and plotted in Figure 8. From the figure, the field strength is seen to be linearly dependent with energizing current with a slope of 6 gauss/ampere.

In a separate series of tests, a hexagonal frame of ¼-inch strips with 5-inch openings replaced the magnetic coil in the above experiment, and magnetic field was varied by changing the number of layers of magnetic sheet strips.

Effect of magnetic field

A magnetic concentrate was slurried to approximately 10% solids in the conical sump, and the slurry was fed to the hydroseparator at a rate of 5L/min (or linear velocity through the tube of 1 cm/sec). When the flow through the system reached steady state, the overflow sample was taken with a container having a volume of 1.75L, filtered, dried, weighed and %solids calculated. The dried samples were assayed for iron.

Initially, magnetic field was applied by energizing the electric coil with a current flow of 2A, allowing the system to come to steady state, and taking the overflow sample for %solids and %Fe determinations. The tests were repeated at 3, 4 and 5 amperes. The results are listed in Table 1 and plotted in Figure 9.

When the field strength was increased to 20 gauss, %solids of the overflow slurry were observed to decrease and changed its color from black to light brownish gray. When the field strength was raised above 20 gauss, magnetite particles of the teeter column were completely arrested at the electric coil. As seen in Figure 9(a), %solids in overflow were at minimum, and the iron contents were lowered to 27%Fe. The amount of the nonmagnetic slimes removed was estimated at 2.3% by weight.

Subsequently, the electric coil was replaced by a hexagonal frame of ¼-inch magnetic sheet strips to apply magnetic field. The number of layers was changed to vary the field

strength. Overflow samples were taken in an identical manner as before, and the results are included in Table 1 and in Figure 1. The field strengths were represented by the minimum values taken at the center of the hexagonal frame. The results were virtually identical to those obtained using an electric coil.

From these observations, it becomes of interest to test if finer adjustments of the field strengths between 10 to 20 gauss may remove some locked siliceous gangue particles preferentially.

The effects of flowrate and slurry density were also investigated by imposing field intensity of 30 gauss using the electric coil. Initially, the slurry density was set at 5% solids and the flowrate at 3 L/min (a linear velocity of 0.6 cm/sec). As indicated by the iron content of the overflow, magnetite particles were fully arrested by the magnetic field. An increase in the slurry density to 10% solids and then in the flowrate to 5, 6 and 7 L/min (linear velocities of 1.0, 1.2 and 1.4 cm/min, respectively) did not change the iron content of the overflow samples, which remained at approximately 26 to 27% Fe. Such an observation indicates that at this field intensity, an increase in the flowrate to the highest setting of the peristaltic pump (7L/min) used did not cause any loss of fine magnetite particles to overflow. An increase in the field intensity to 60 gauss did not substantially change the results.

EFFECT OF MAGNETIC FIELD ON FLOTATION

Test setup and procedure

Installation of a magnetic gridwork in a 2-liter Denver laboratory flotation cell presents a problem because of its small size, and hence a 5-liter Plexiglas cell was used. A 3-inch by 3½-inch rectangular grid of ¼-inch magnetic sheet strips was fitted inside the cell, and an outside frame of ¼-inch magnetic sheet strips was placed to raise the field intensity around the cell wall so that a relatively uniform distribution of the field intensities over the flotation surface may be achieved. A schematic diagram of the gridwork is shown in Figure 10.

A mild steel frame with a cut-away opening corresponding to the diameter of the impeller shaft is first placed inside the flotation cell, and then ¼-inch magnetic sheet strips were placed on its top in layers at a level where the pulp/froth interface is expected to be located. A typical example of minimum field intensity in each opening with 3 layers of magnetic sheet strips inside and 2 layers outside is indicated in Figure 10. In this example, the average is calculated to be 80 ± 8 gauss. Field intensities with other combinations are given in Table 2.

Flotation tests were carried out by placing a sample, typically 3,000-gram wet, in the cell first, then placing the magnetic gridwork, and adding water to volume (40%solids). The flotation reagents were added in sequence of MIBC, conditioning for 30 seconds, then of MG82, conditioning for 1 minute, and turning on the air at 60 mL/min. Froths were collected by changing the froth-receiving pan at 1 and 2 minutes, so that the froths of 0

to 1, 1 to 2, and 2 to 3 minutes were collected separately in an attempt to study the flotation rate. Then another dose of MG82 was added and the tests repeated to study the effect of stage addition of the collector.

After the test, the material attached to the grid was collected and, together with the flotation products, was dried, weighed and assayed for iron and silica.

Test results

Initially, flotation tests were performed to study the effect of magnetic field strength at 40% solids. The imposition of magnetic field decreased the weight recoveries progressively with increasing field strength, but when the test data were replotted in the form of grade-recovery curves, very little improvement was noted in the selectivity of flotation separation. The levels of the collector addition and its stage addition, as well as desliming of the feed sample, had virtually no effect on the selectivity of separation.

During the flotation, it was observed that even though agitated pulps were effectively held down by the magnetic gridwork, magnetite-rich pulps broke through the grid occasionally by the agitation of the impeller and collected in the froths. This was thought to be due to the high pulp density in the flotation cell. A series of tests was performed by lowering the pulp density to 30% solids.

A 2,000-gram (wet) sample was pulped in the flotation cell (30%solids), conditioned with 0.06 lb/lt MIBC for 30 seconds, followed by conditioning with 0.05 lb/lt MG82 for 1 minute, and froth was collected for 0 to 1, 1 to 2, and 2 to 3 minutes separately. Then, an addition of 0.05 lb/lt MG82 followed by the same flotation procedure was repeated twice. When the magnetic gridwork was installed, substantial amounts of the material became attached to the grid and were not collected in the flotation products. In an attempt to minimize the loss of samples, the grid was pre-coated by conditioning a sample with frother and collector, stopping the agitation and siphoning out the sample in the cell, thereby leaving behind the grid coated by magnetite equilibrated with the frother and collector. Then a fresh 2,000-gram sample was charged to the flotation cell, and the flotation test was performed in the same manner as before.

Figure 11 shows a plot of %weight in cell product as a function of flotation time. The figure shows that 3-minute flotation is sufficiently long to recover essentially all the floatable material at a given collector addition, and less material floats as higher magnetic field strengths are imposed. Figure 12 shows a grade-recovery plot of Fe recovery vs. %SiO_2 in flotation concentrates. It is apparent that the data points are virtually coincident up to 80 gauss, whereas the data points at 109 gauss are more selective than the other conditions. Apparently, lowering the pulp density to 30% solids was helpful in preventing spurious rises of magnetite-rich pulps above the magnetic grid work. It becomes of interest to modify the design of the gridwork and to place it at a proper level so that the accidental mixing of magnetite-rich pulps to the froth layer may be controlled more effectively.

SUMMARY

The use of magnetic gridwork was shown to increase the water rates in a laboratory hydroseparator, thereby allowing more efficient desliming, and to prevent the losses of fine, high-grade magnetite particles in flotation. The device is simple in construction, low-cost and may be installed readily in existing equipment.

Unusually persistent and stable flotation froths in certain taconite plants may stem from the presence of some layered clay-type minerals. Thorough desliming ahead of flotation in a hydroseparator using this device will reduce the reagent dosage, thereby alleviating the froth problem. The use of the device will arrest the fine, high-grade magnetite in flotation and will not only prevent excessive losses of iron units in achieving the final concentrate grades, but will also improve balling by keeping more fines in the final concentrates.

A research proposal has been submitted to the Permanent University Trust Fund to test this device in pilot-scale hydroseparator and in continuous flotation cells for demonstrating their effectiveness in minimizing iron losses from magnetic concentrate processing, and to collect design parameters needed for plant trials.

REFERENCES

Roe, L.A., 1953, Magnetic Reflux Classifier, Mining Eng., vol 5, 312-315.

Seetharama, V.N., Malicsi, A.S., and Iwasaki, I., 1991, Effect of Magnetic Fields in the Flotation of Magnetic Concentrates, in Final Report to the State of Minnesota and the American Iron and Steel Institute, Mineral Resources Research Center, University of Minnesota.

Sonolikar, R.L., Mandlekar, V.A., and Gaidhani, S.B., 1988, Effect of Magnetic Field on Column Flotation of Ore Containing Magnetic Content, Column Flotation '88, K.V.S. Sastry, Ed. SME Annual Meeting, Phoenix, Az, January 25-28, 1988.

Wu, C., Benner, B., and Bleifuss, R., 1995, The Flotation of Taconite in a Magnetic Field, Proceedings, Minnesota Section SME 68th Annual Meeting, Center for Professional Development, University of Minnesota-Duluth, Duluth, Minnesota, 245-256.

Table 1. Effect of Magnetic Field on Laboratory Hydroseparator Operation

(1) Effect of Magnetic Field Strengths
10% solids, 5 L/min (1 cm/sec)

Electromagnet				Magnetic Sheet (hexagonal)			
Current	Field	Overflow		No. of	Field	Overflow	
(A)	(gauss)	% solids	%Fe	sheets	(gauss)	% solids	%Fe
0	0	9.4	67.5	0	0	(9.4)	(67.5)
2	12	6.9	66.7	1	7	5.9	66.9
3	18	0.77	48.8	2	14	2.5	63.9
4	24	0.23	27.4	3	21	0.19	29.4
5	30	0.19	26.6	4	27	0.11	27.2

(2) Effect of Flowrates with Electromagnet

Current	Field	Flowrate		Slurry	Overflow
(A)	(gauss)	L/min	cm/sec	% solids	% Fe
0	0	3	0.6	5	64.5
5	30	3	0.6	5	28.2
5	30	3	0.6	10	26.8
5	30	5	1.0	10	25.8
5	30	6	1.2	10	26.8
5	30	7	1.4	10	27.7
10	60	7	1.4	10	26.3

Table 2. Effect of Number of Layers of Magnetic Sheets on Field Intensity in Laboratory Denver Flotation Cell

Number of Layers			Field Intensity (gauss)
	Outside		
Inside	Side and Back	Front	
1	1	2	30 ± 4
2	1	2	54 ± 5
3	2	2	80 ± 8
4	2	3	88 ± 6
5	3	4	109 ± 6
6	3	3	133 ± 15

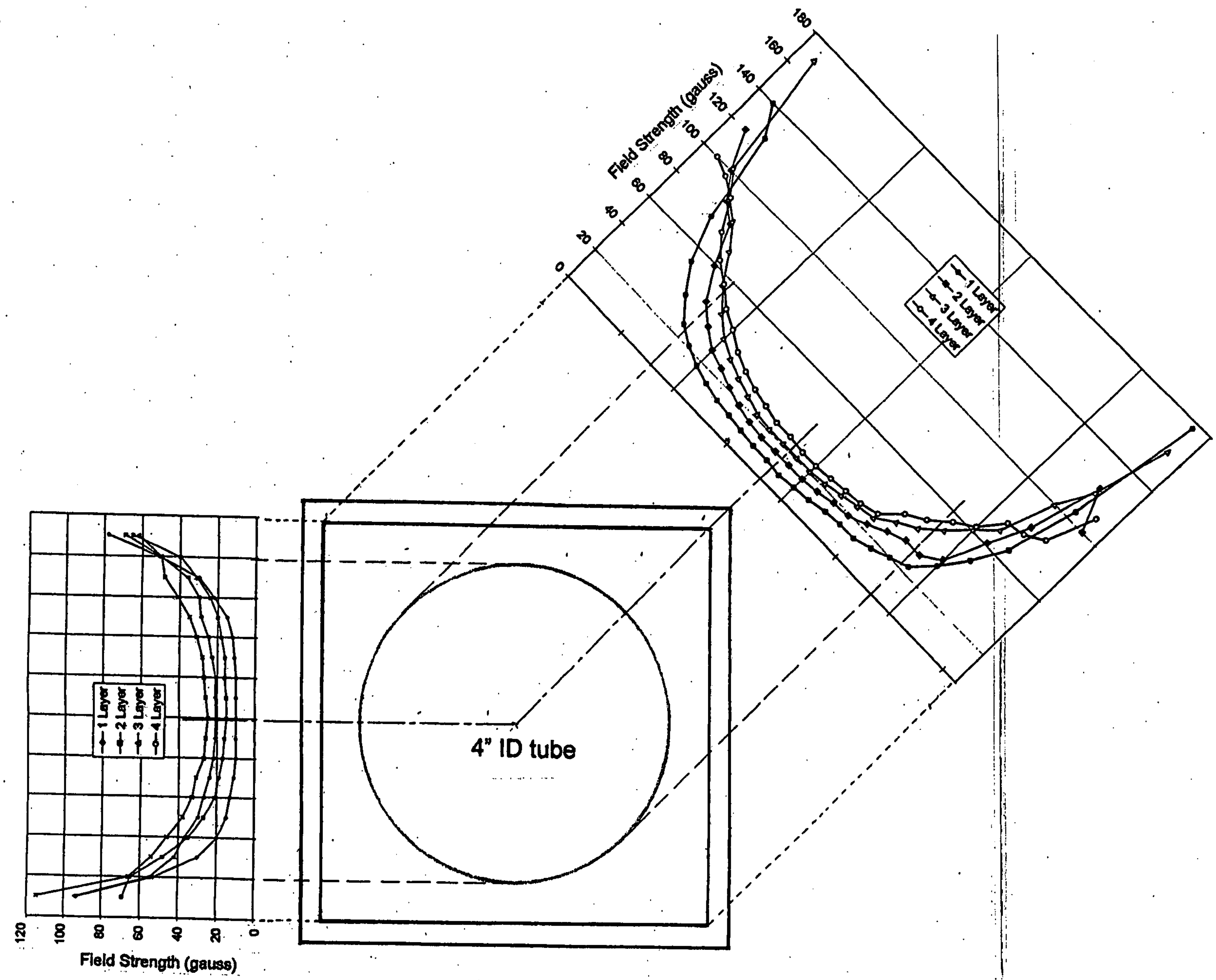

Figure 1. Magnetic field strength distribution inside a 5-inch square frame of 1/4-inch strips showing the effect of the number of layers

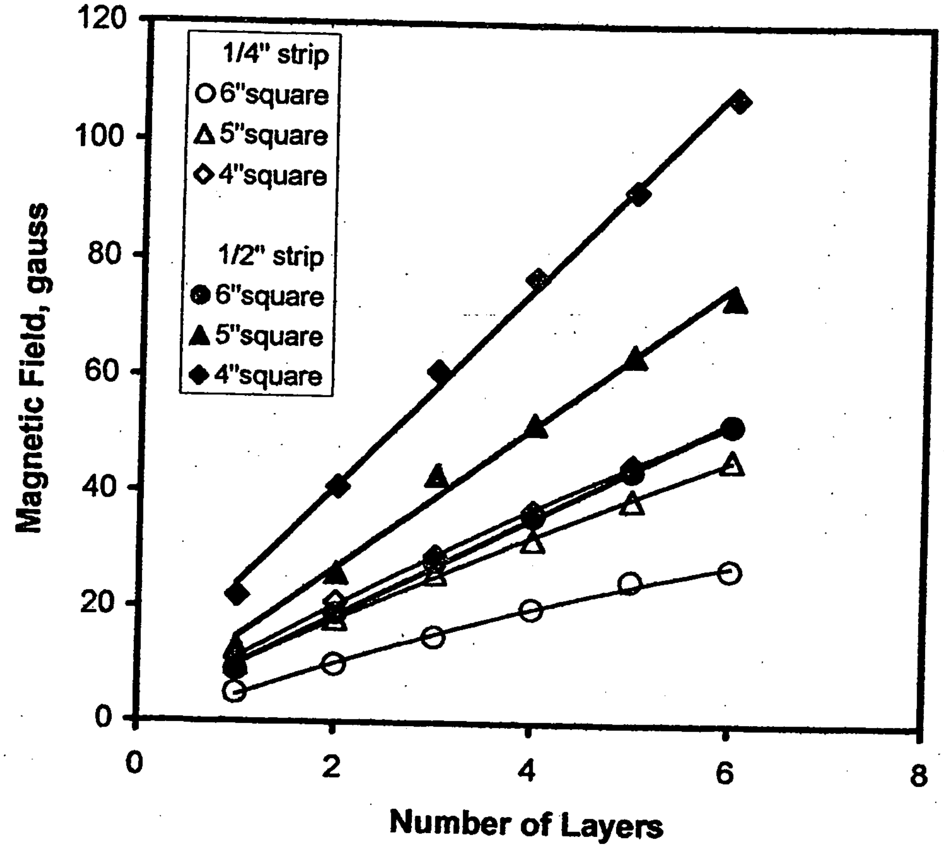

Figure 2. Magnetic field strengths as a function of the number of layers for 1/4- and 1/2-inch strips with inside openings of 4, 5 and 6 inches

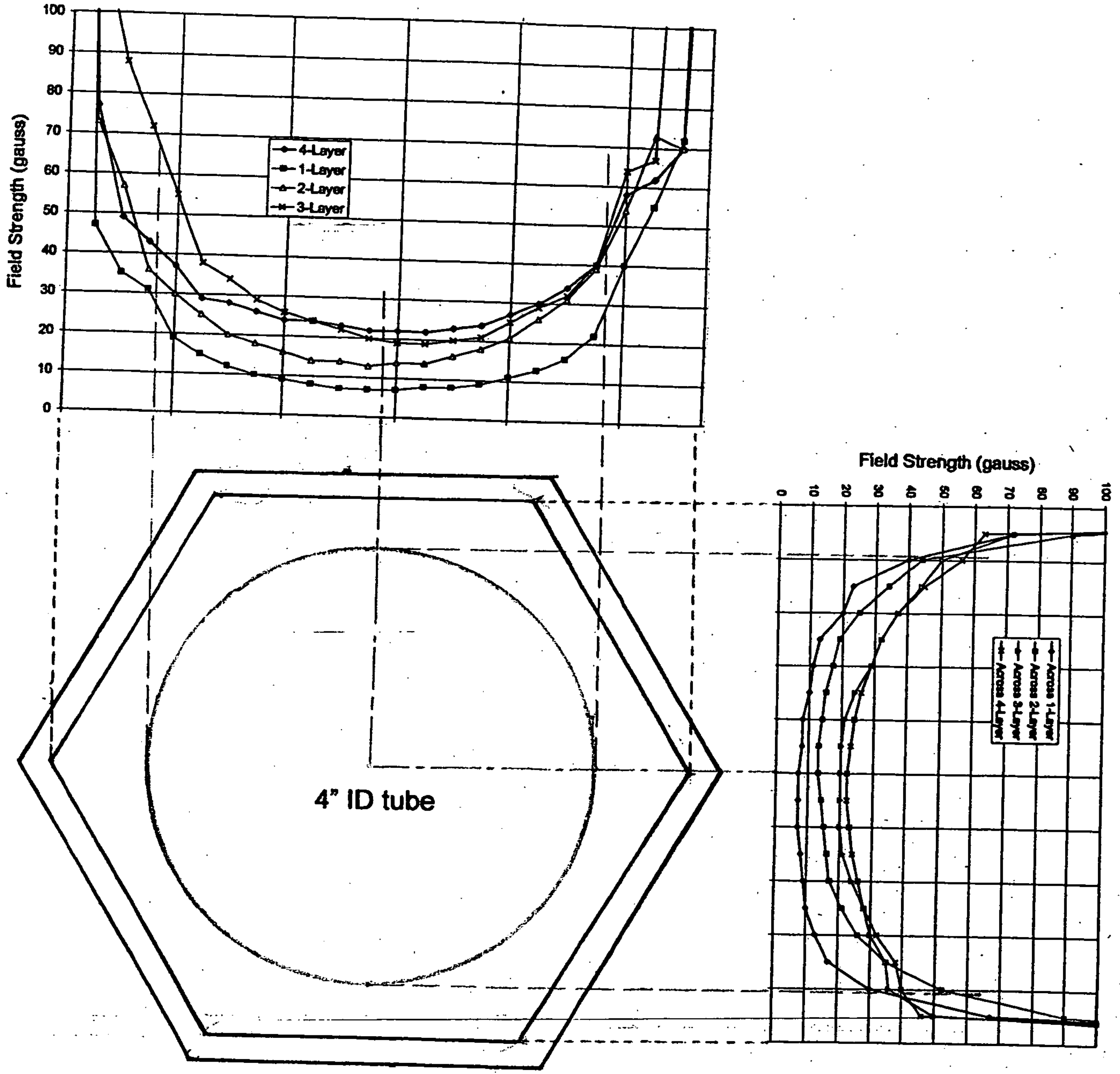

Figure 3. Magnetic field strength distribution inside a hexagonal frame of 1/4-inch strips with 5-inch openings showing the effect of the number of layers

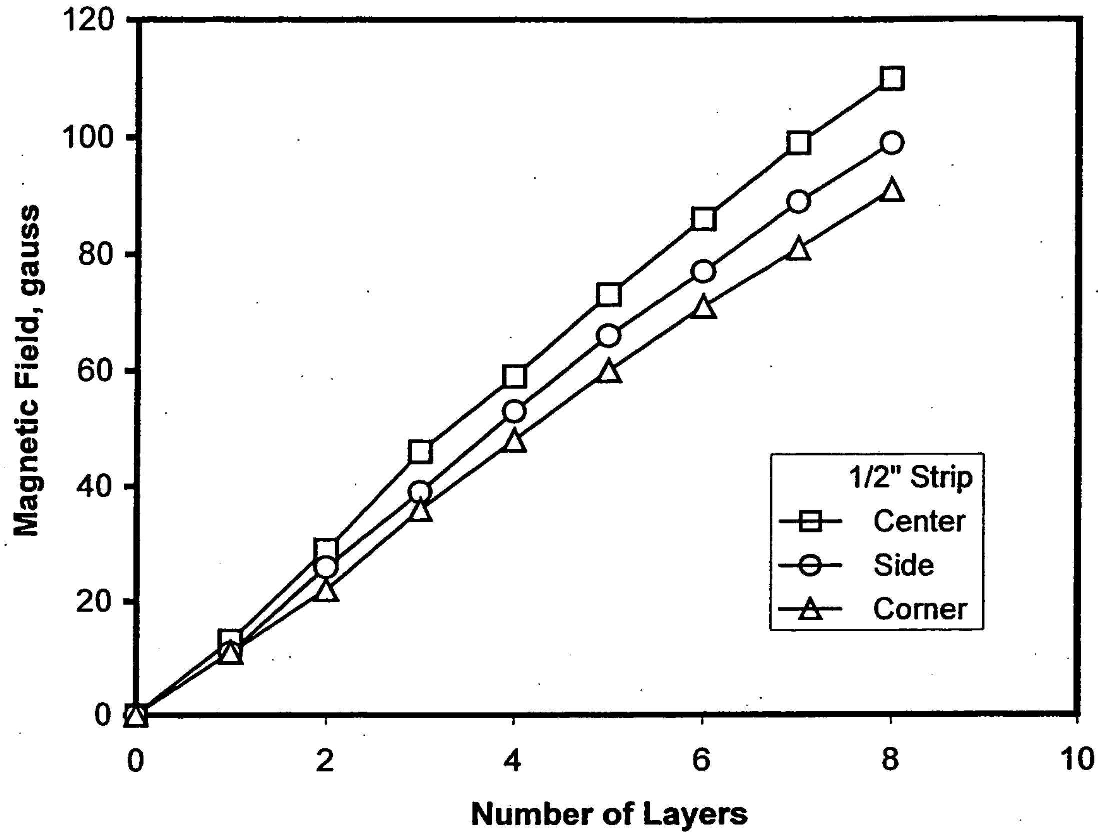

Figure 4. **Magnetic field strengths at the centers of middle, side and edge squares of a nine-opening square frame of 1/2-inch strips with 6-inch openings showing the effect of the number of layers**

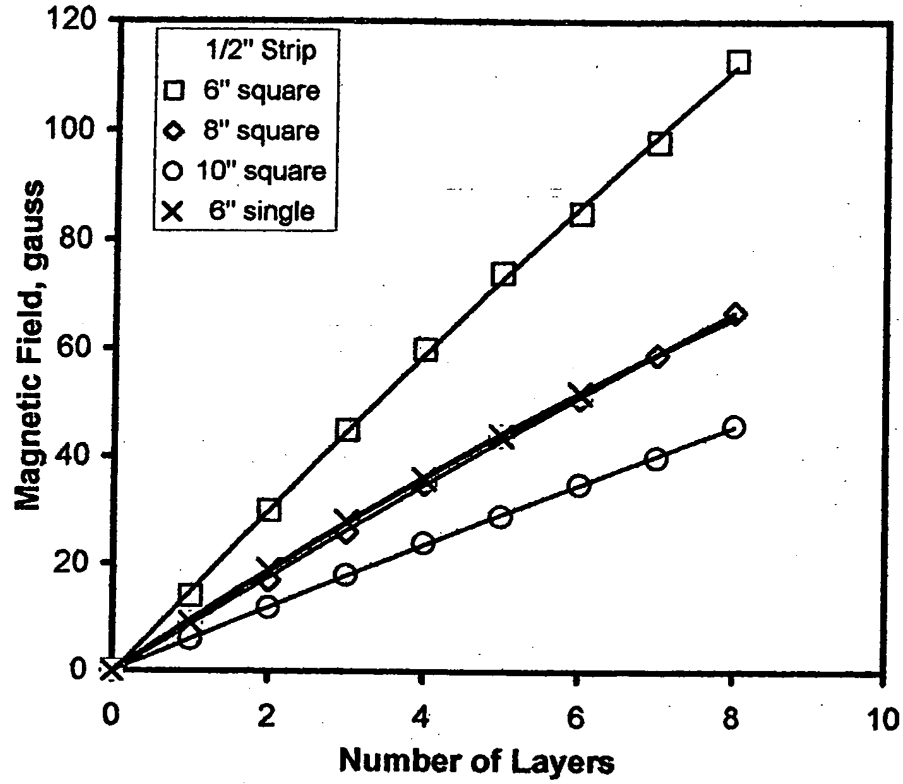

Figure 5. Magnetic field strengths at the centers of middle squares of a nine-opening square frame of 1/2-inch strips with 6-, 8- and 10-inch openings showing the effect of the number of layers. The field strengths of a single square with 6-inch opening are included for comparison.

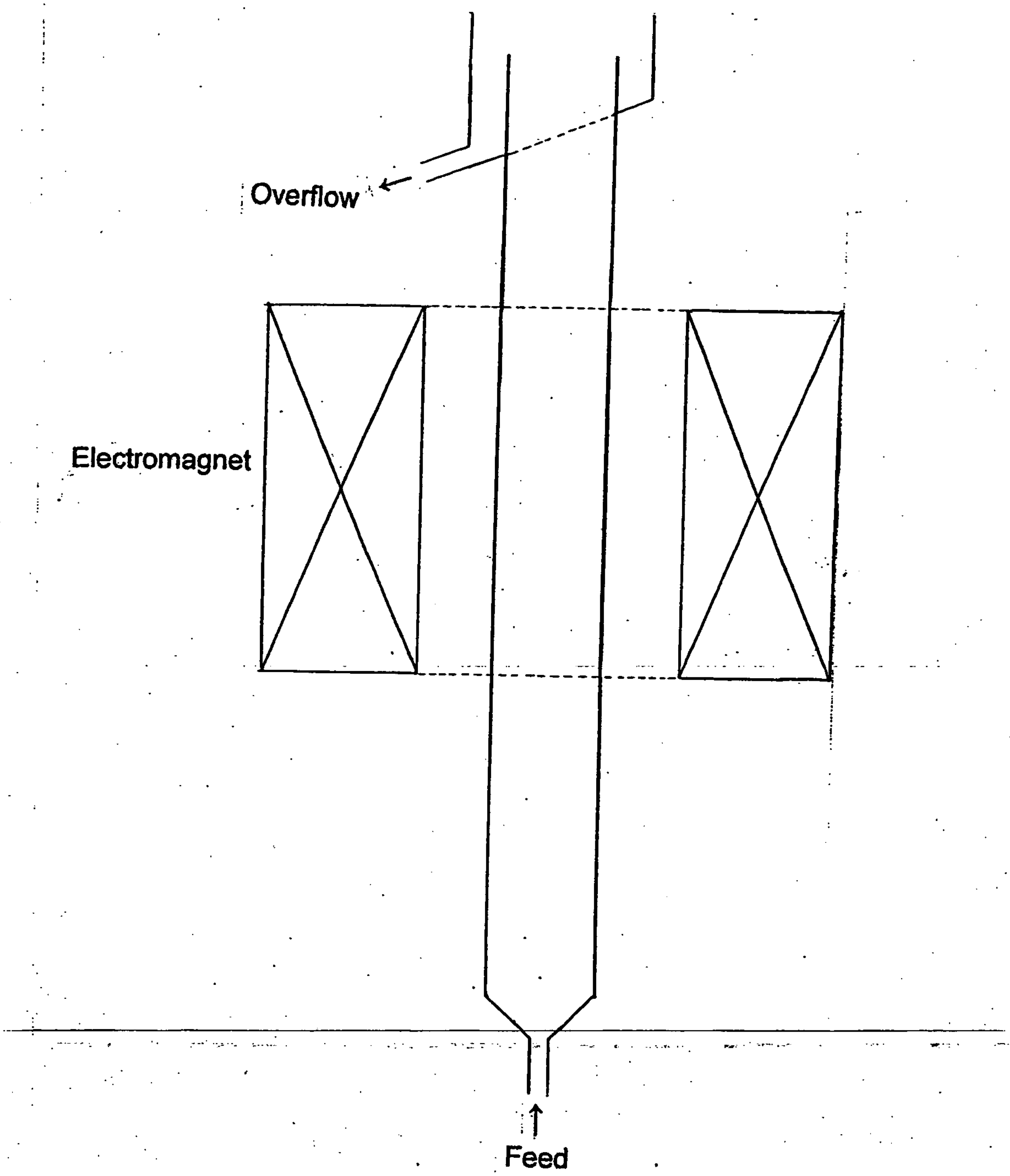

Figure 6. **Schematic diagram of laboratory hydroseparator setup**

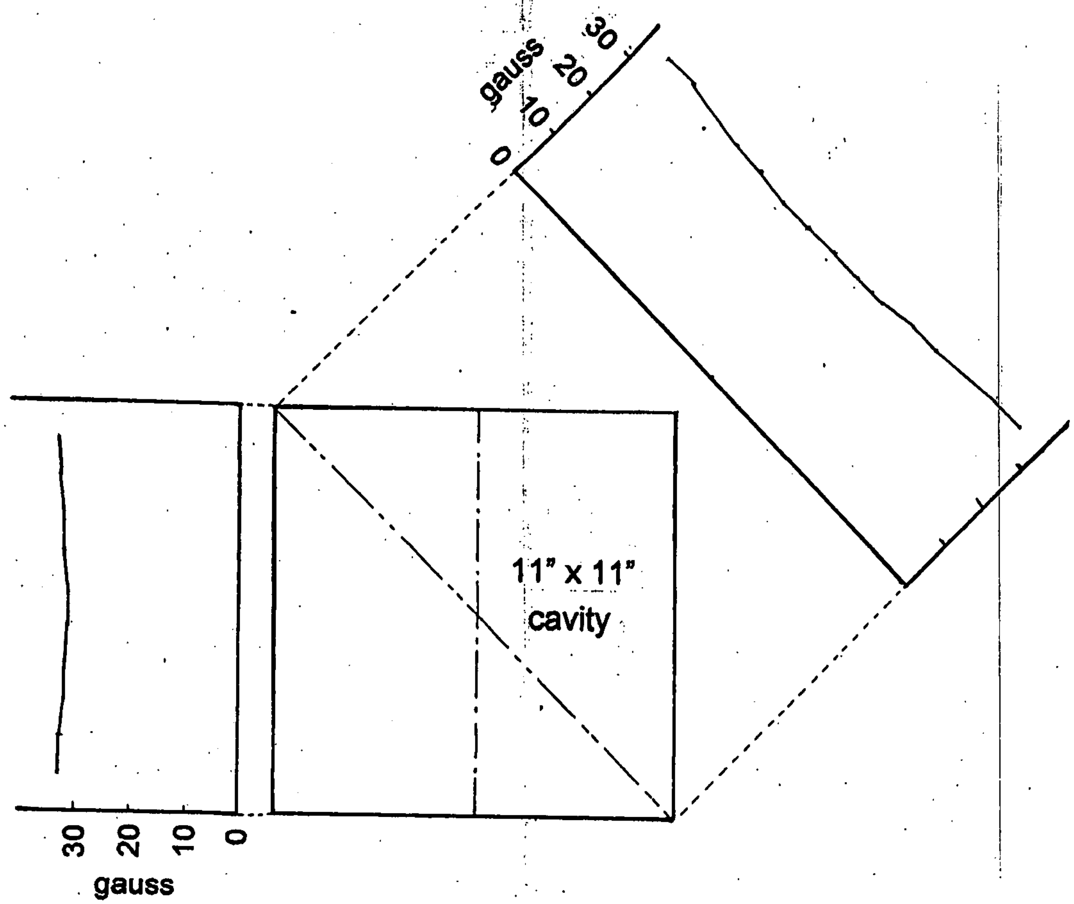

Figure 7(a). Magnetic field strength distribution at center in horizontal direction of electromagnet at energizing current of ZA.

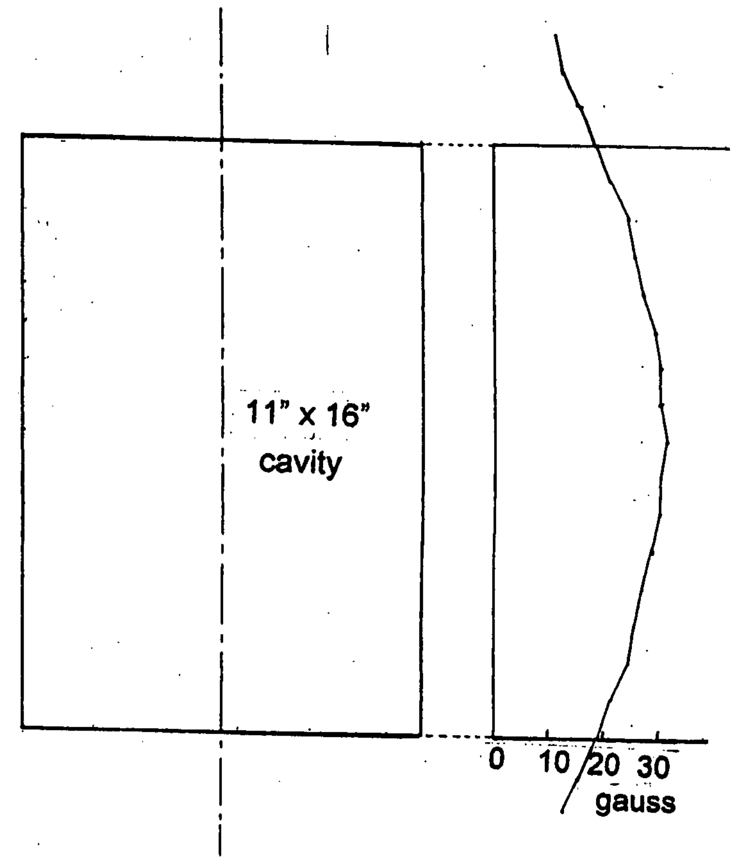

Figure 7(b). Magnetic field strength distribution at center in vertical direction of electromagnet at energizing current of ZA.

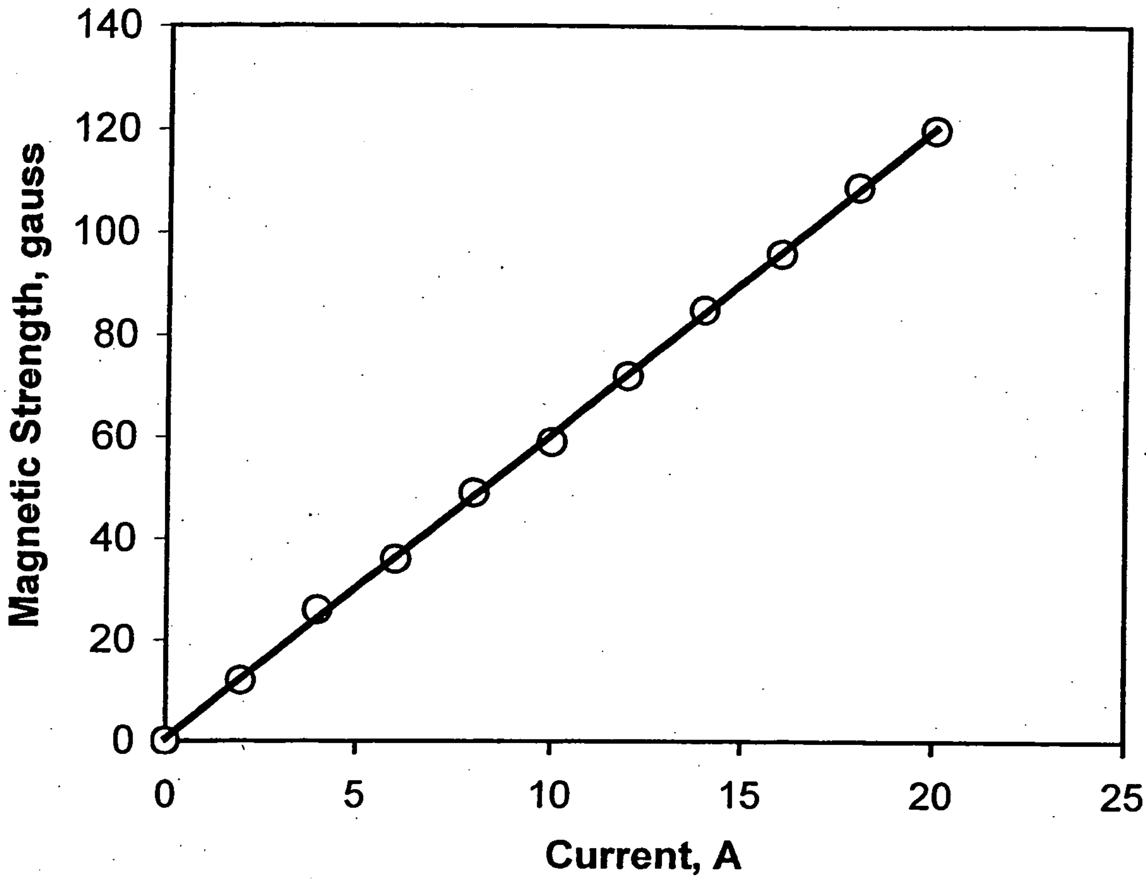

Figure 8. **Magnetic field strengths at center of electromagnet as a function of energizing current**

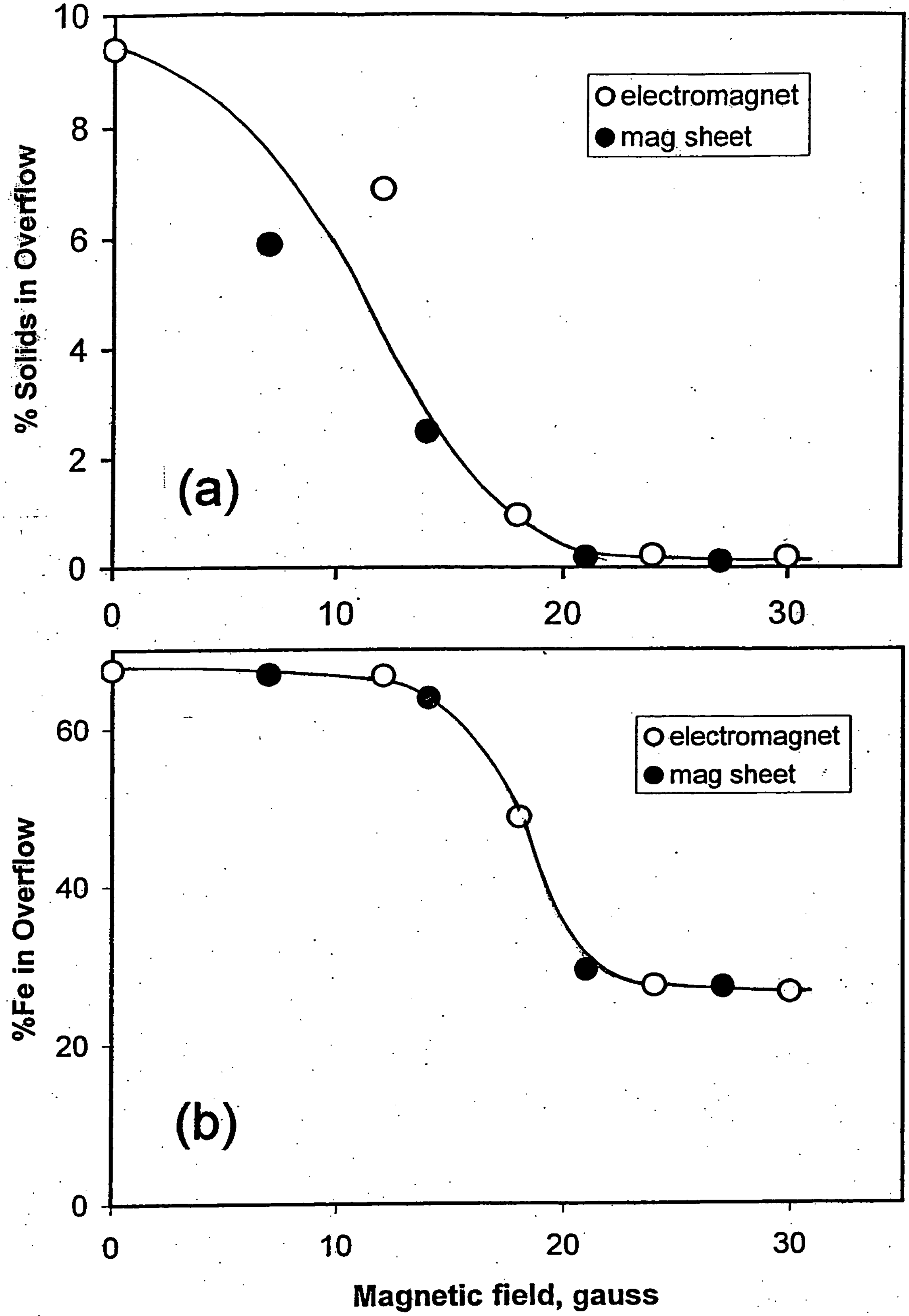

Figure 9. **Effect of magnetic field on laboratory hydroseparator operation. (a) Effect of magnetic field strength at 10% solids and 5 L/min; (b) Effect of flowrates with electromagnet.**

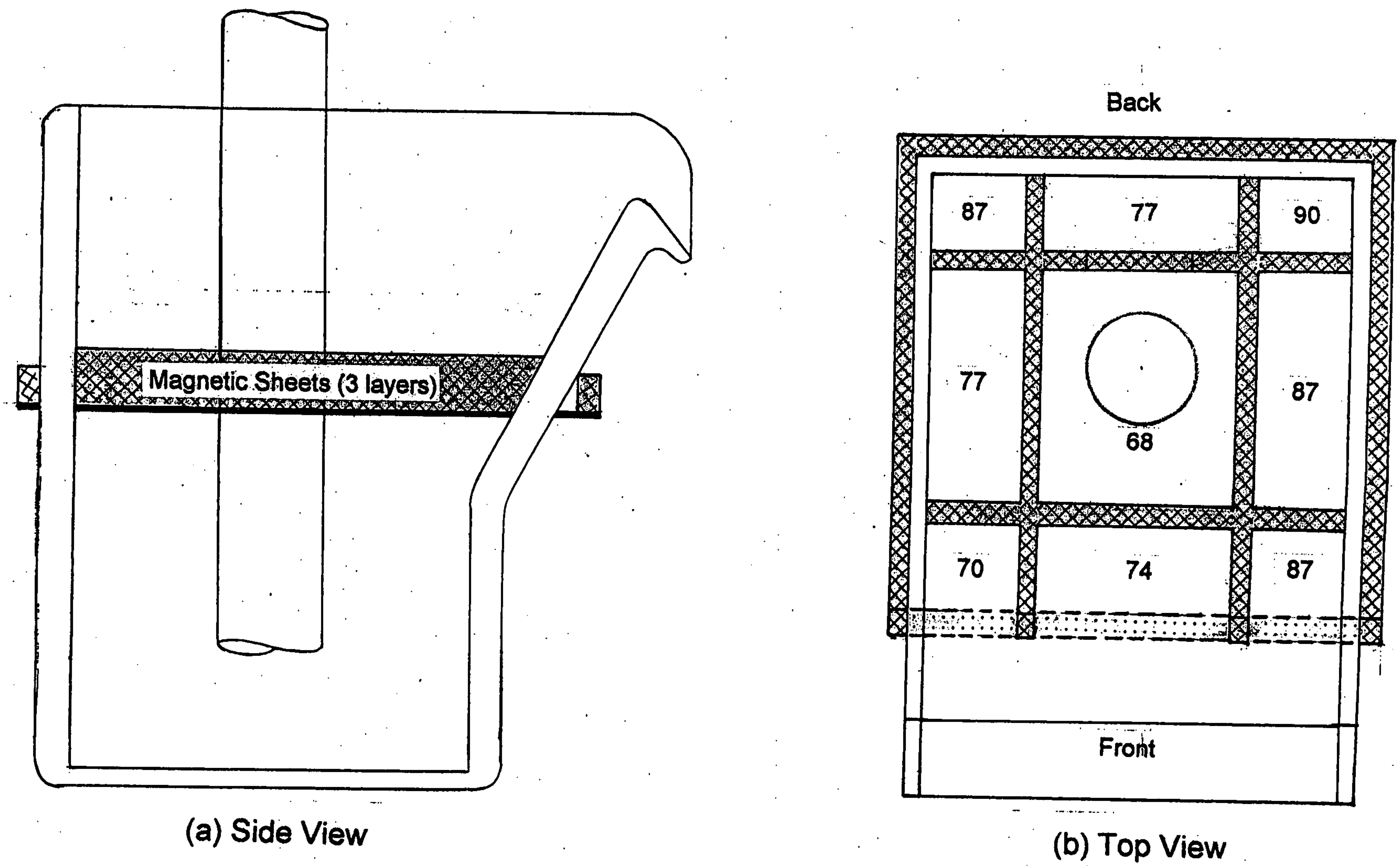

Figure 10. Schematic diagram of gridwork placed in a laboratory Denver flotation cell (Magnetic sheets: 3 layers inside, 2 layers outside; the numbers refer to the lowest magnetic strength in each opening)

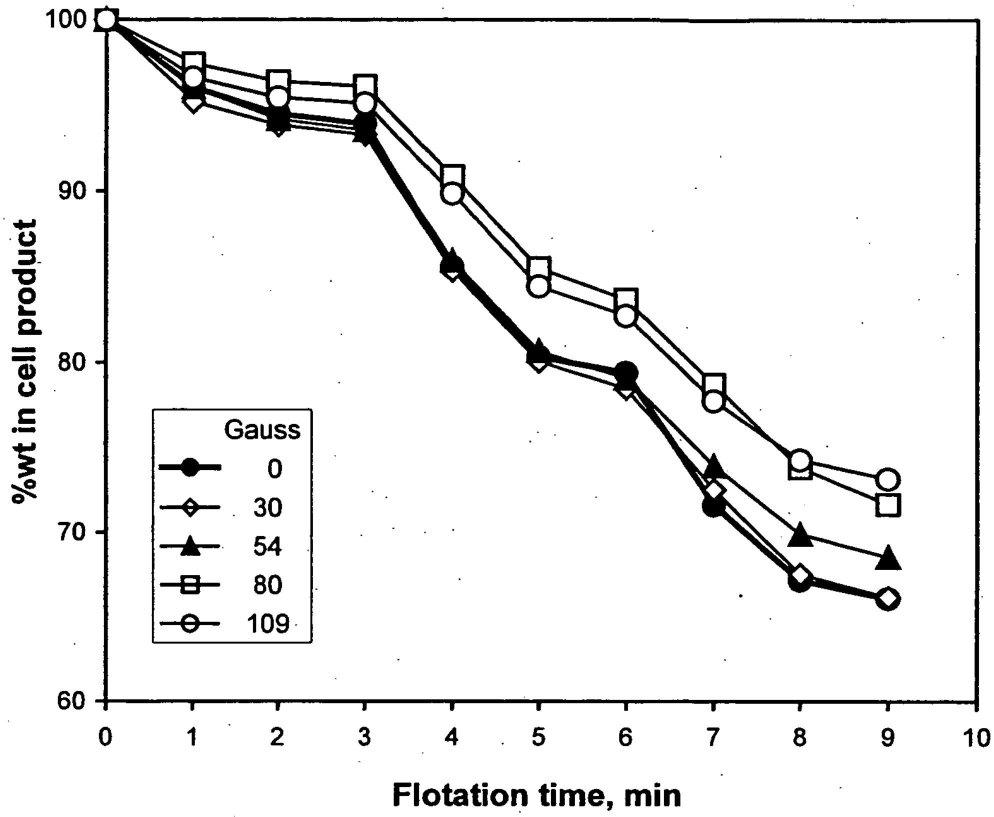

Figure 11. **Effect of magnetic field on % weight recovered in cell product as a function of flotation time**

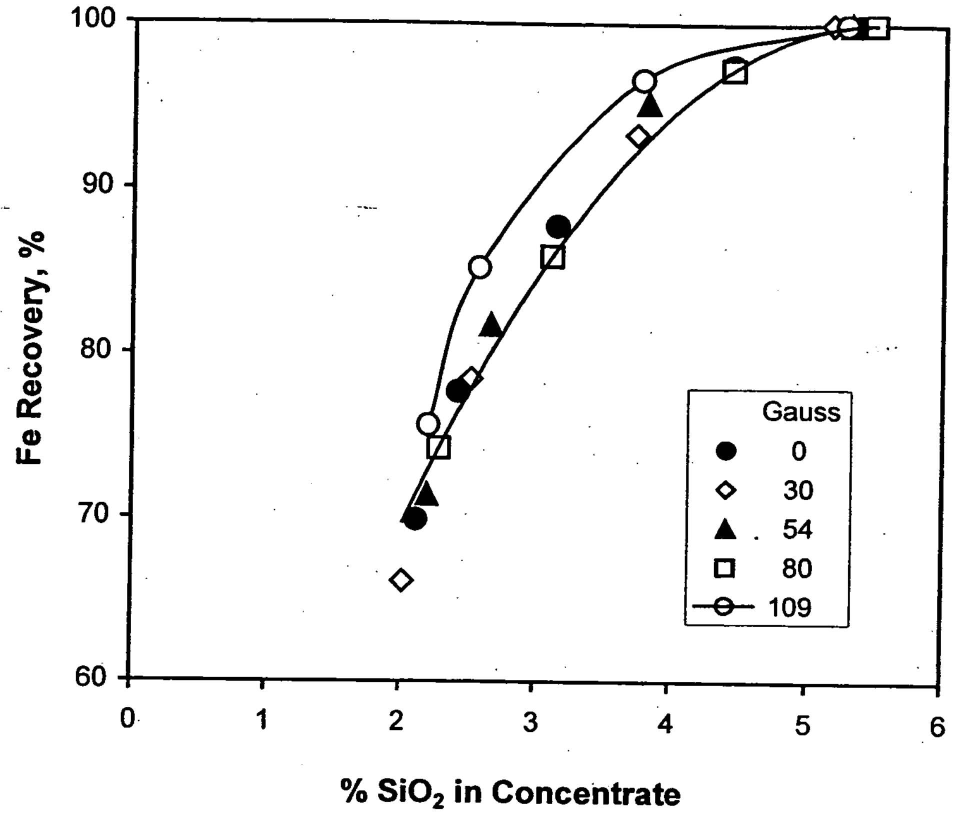

Figure 12. Effect of magnetic field on flotation results shown as grade-recovery plots of Fe recovery against % SiO_2 in flotation concentrates

Exhibit B

Final Report

EFFECT OF MAGNETIZING / DEMAGNETIZING ON CATIONIC SILICA FLOTATION UNDER A MAGNETIC FIELD

COLERAINE MINERALS RESEARCH LABORATORY

October 17, 2001

CONFIDENTIAL

By

Iwao Iwasaki
Senior Research Associate
Endowed Taconite Chair

And

Salih Ersayin
Program Director
Concentrator Modeling and Simulation

CMRL/TR-01-20
NRRI/TR-2002/04
Project #5601104 & 5698106

Sponsored by the Permanent University Trust Fund and Endowed Taconite Chair

University of Minnesota Duluth
Natural Resources Research Institute
5013 Miller Trunk Highway
Duluth, Minnesota 55811

Coleraine Minerals Research Laboratory
P O Box 188
One Gayley Avenue
Coleraine, Minnesota 55722

Effect of Magnetizing/Demagnetizing on Cationic Silica Flotation Under A Magnetic Field

Abstract: In the presence of a magnetic field in the flotation cell, the "as received" sample was sufficiently magnetized and no further benefit was gained by magnetizing treatment. Selectivity of separation was somewhat adversely affected by demagnetizing of the "as received" sample, though its effect was minimal due to the magnetic field.

INTRODUCTION

In a recent investigation, application of a magnetic field in a 50 cu.ft. WEMCO flotation cell was shown to be effective in controlling iron losses in cationic silica flotation. Major losses in iron units in froth products were in the –500 mesh fraction, and the application of a magnetic field decreased the flotation of fine magnetite, thereby improving the selectivity of separation. In these tests, an "as received" sample was used.

It is well known that magnetizing and demagnetizing of magnetic concentrates profoundly affect their flotation behaviors. The purpose of the present investigation was to test if, in the presence of a magnetic field, magnetizing treatment may further improve the recovery of the –500 mesh fraction by inducing magnetic flocculation. Alternatively, demagnetizing treatment may release occluded middling particles, thereby improving selectivity.

TEST PROCEDURE

A plant flotation feed sample, dated May 30, 2001, was received in six 55-gallon drums from the U.S. Steel Minntac plant and designated as NRRI 2801. Head analyses and size distribution are given in Tables 1(a) and 1(b). Three tests were performed. In one test, a flotation test was performed on the "as received" sample using an identical procedure reported in a previous report under optimal conditions (magnetic gridwork with 6 layers of magnetic sheets) in order to establish base flotation data.

Then a flotation test was performed on a feed sample thoroughly magnetized using a magnetizing coil operating at 50A DC, followed by another test on a sample thoroughly demagnetized using the same magnetizing coil operating with 220V AC, for comparison.

TEST RESULTS

Test results are plotted in the form of grade-recovery curves in Figure 1. It is seen that the curves with the "as received" and magnetized samples parallel each other

and are quite similar. With the demagnetized sample, the composited head SiO_2 analysis was appreciably lower than the other two samples, and the grade-recovery curves could not be compared directly, yet the curve appeared to be somewhat steeper. In an attempt to bring out the selectivity of separation more clearly, differences between the analytical values of SiO_2 for samples processed at different times were subtracted from respective composited heads, which were termed "delta SiO_2" in this report. Then, iron recoveries are plotted against "delta SiO_2" in Figure 2. It is now apparent that the selectivity of separation was adversely affected by demagnetizing the feed sample.

The degree of flocculation of the three types of pulps was characterized by determining the settling rates of the feed suspensions. The settling velocities are listed in Table 2. It is rather puzzling that the magnetizing treatment lowered the settling rate though to a minor extent. However, such behavior appears to support somewhat lower selectivity of separation with the magnetized sample as compared to the "as received" sample.

Size analyses of the froth products and final concentrates of the three tests were made, and the distributions of iron and silica units in different size fractions were calculated. Detailed calculation results are given in the Appendix. Iron losses to different size fractions of total froths expressed as percentages of the total iron units in the feed sample are plotted as a bar graph in Figure 3. As before, the major losses of iron units occurred in the –500 mesh fraction. However, differences between magnetizing and demagnetizing treatments were relatively minor in every size fraction. Apparently, the presence of a magnetic grid minimized the effects of magnetizing and demagnetizing treatments.

The effect of magnetite particles attached to the magnetic grid on magnetic field strengths was determined. With 6 layers of magnetic sheets, the magnetic field strengths at the center of each square averaged 64±11 gauss in the absence of attached magnetite, whereas with magnetite attached, the field strengths decreased to 33±4 gauss, or a reduction of 47±14%. Then, the amount of magnetite attached to the magnetic grid was determined by washing it off with a strong water jet, then drying and weighing the solids. The magnetite thereby removed amounted to 60 kg, or approximately 22% of the solids in the cell of about 275 kg. The sample analyzed 68.0% Fe and 4.79% SiO_2. Its size distribution was essentially identical to the final concentrates.

CONCLUSIONS

1. The "as received" sample was sufficiently magnetized and no further benefit was gained by magnetizing treatment.

2. Demagnetizing of the "as received" sample led to somewhat lower selectivity of separation.

3. The magnetic grid acquired a coating approximately ½-inch thick of magnetite particles, which amounted to about 20% of the solids in the flotation cell, and the magnetic field strength at the center of each square decreased by a little less than 50%.

4. It becomes of interest to test the application of a magnetic field in the form of a magnetic grid in a continuous mode in order to examine if the magnetite attached to the magnetic grid tends to grow and the magnetic field strengths in the openings decrease.

REFERENCE

Iwasaki, I., and Ersayin, S., 2001, Magnetic field application in cationic silica flotation, Final Report, Coleraine Minerals Research Laboratory, Natural Resources Research Institute, University of Minnesota-Duluth, CMRL/TR-01-04, NRRI/TR-2001/14, 39p.

Table 1. Head and Screen Analysis Data on Minntac Plant Flotation Feed Sample (05-30-01) Used in Flotation Tests

a) Head analysis results

% Fe	% SiO_2
67.2	5.65

b) Screen analysis results

Size, mesh	% Weight	% Fe	% SiO_2
150	0.5	39.0	37.79
200	2.6	42.6	32.76
270	10.1	58.9	14.75
400	14.8	66.4	6.51
500	16.4	69.4	3.37
-500	55.6	70.0	2.67
Composite	100.0	67.4	5.53

Table 2. Settling Rates of "As Received," Magnetized and Demagnetized Flotation Feed Samples

Sample	Settling Rate cm/min
As received	35.9
Magnetized	33.1
Demagnetized	28.7

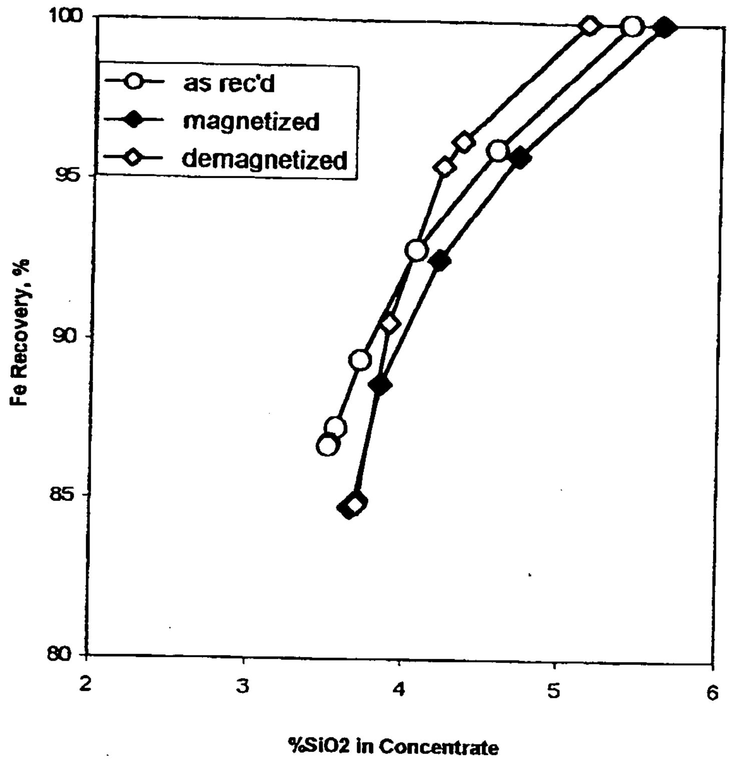

Figure 1. Grade-recovery plots showing the effects of magnetizing and demagnetizing on batch flotation tests (Magnetic gridwork with 6 layers of magnetic sheet)

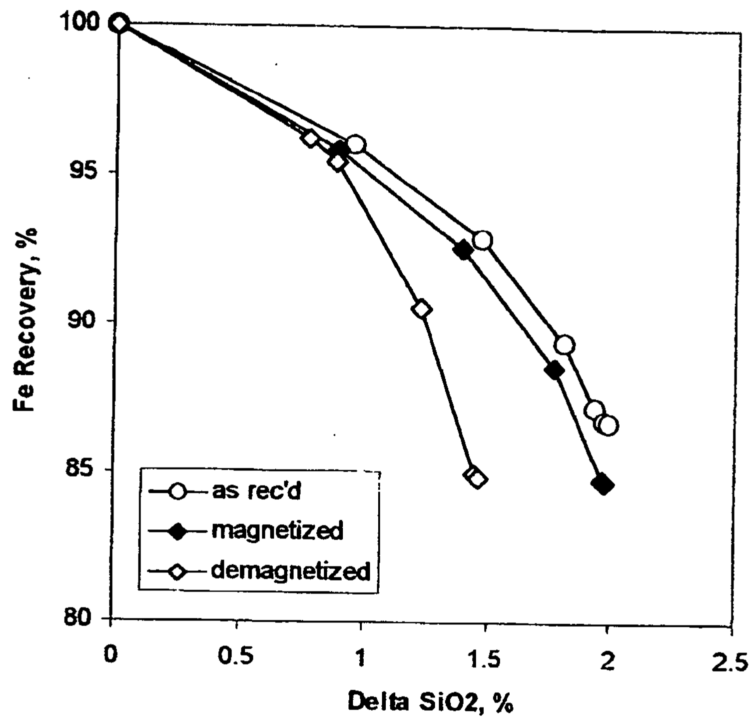

Figure 2. Grade-recovery plots in terms of "delta Silica" showing the effects of magnetizing and demagnetizing on batch flotation tests (Magnetic gridwork with 6 layers of magnetic sheets)

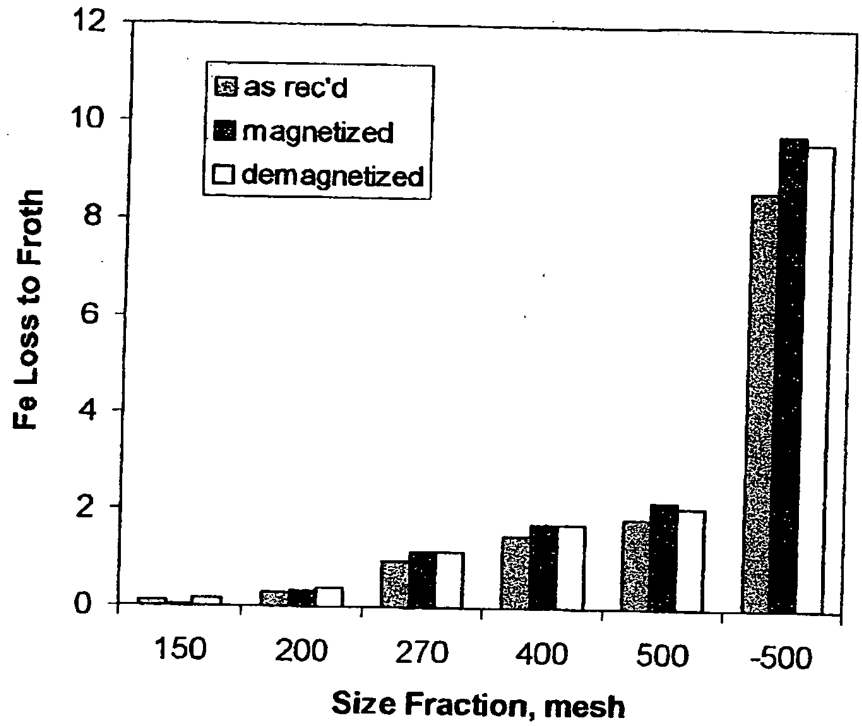

Figure 3. Iron losses to different size fractions of total froths expressed as percentages of the total units in feed sample

Exhibit C

Final Report

MAGNETIC FIELD APPLICATION IN CATIONIC SILICA FLOTATION

COLERAINE MINERALS RESEARCH LABORATORY

May 4, 2001

CONFIDENTIAL

By Iwao Iwasaki
Iwao Iwasaki
Senior Research Associate
Endowed Taconite Chair

By Salih Ersayin
Salih Ersayin
Program Director
Concentrator Modeling and Simulation

CMRL/TR-01-04
NRRI/TR-2001/14
Project #5601104 & 5698106

Sponsored by Permanent University Trust Funds and Endowed Taconite Chair

University of Minnesota
Natural Resources Research Institute
5013 Miller Trunk Highway
Duluth, Minnesota 55811

Coleraine Minerals Research Laboratory
P O Box 188
One Gayley Avenue
Coleraine, Minnesota 55722

Magnetic Field Application in Cationic Silica Flotation

Abstract: Application of a magnetic field was shown to be effective in controlling the iron losses in pilot-scale cationic silica flotation in processing magnetic taconite concentrates. The design of a magnetic field distribution device and certain batch flotation test results using a 50 cu.ft. WEMCO cell are reported. Major losses of iron units in froth products were in the –500 mesh fraction, and the application of a magnetic field decreased the flotation of fine magnetite particles, thereby improving the selectivity of separation. The device is simple in construction, low cost and may be installed readily in existing equipment. Continuous flotation testing is recommended to collect necessary information for plant trials.

INTRODUCTION

In the cationic silica flotation of magnetic taconite concentrates, iron losses are high due to simultaneous flotation of fine, well liberated, high-grade magnetite along with coarse middlings locked with magnetite. Much interest has been expressed by the iron ore industry to develop a means of minimizing the flotation of fine, high-grade magnetite.

Intensive efforts have been made over the years attempting to develop more selective collectors and depressants to remove silica from magnetic taconite concentrates, but the results have been disappointing, and some reagents may even become of environmental concern in tailing ponds. A magnetic field may be used to depress magnetic minerals, and its use is attractive not only for low cost, but also for no effect on the environment.

The use of a magnetic field in flotation was first reported on a copper sulfide ore for reducing the recovery of magnetic minerals (pyrrhotite and magnetite) by using an electromagnet coil around a laboratory column flotation cell (Sonolikar et al.,1988). The magnetic minerals were shown to be arrested in the magnetization zone though only low aeration rates were found to achieve in low magnetics contents in the froths. Higher air flowrates disturbed the captured magnetic particles, thus allowing them to float into the froths. In laboratory–scale tests, the use of electromagnets is convenient in varying the field strengths at will. However, for commercial-scale equipment, the use of electromagnets will be impractical with respect to size, design and safety.

Seetharama et al. (1991) carried out a series of tests on magnetic taconite concentrates, applying magnetic fields to laboratory Denver and WEMCO flotation cells. Several configurations of permanent magnets, both static and dynamic, have been investigated with promising results. Using a laboratory flotation cell converted into a continuous flotation unit, they showed that fine magnetite particles were effectively depressed and the selectivity of separation was markedly improved.

Wu et al. (1995) tested the use of an electromagnet coil on an 8-inch diameter flotation column. Encouraged by the preliminary test results, they extended the tests using permanent magnets around the flotation column and then in a 50-cu.ft. WEMCO flotation cell. In these tests, ½-inch thick magnetic sheets were placed parallel facing each other vertically and an aluminum frame held the sheets in place. They found that iron recoveries increased with field intensities up to 100 gauss, and further increase did

not improve the iron recovery significantly; permanent magnetic sheets were shown to be used as effectively as an electromagnet; the magnetic field needs to be applied to the pulp/froth interface; and magnetic sheets should cover the entire flotation surface. However, plant trials of placing magnetic sheets in mechanical flotation cells experienced operational difficulties and tests had to be discontinued.

In Progress Report No. 1, dated August 10, 2000, a magnetic field distribution device (patent disclosure filed with the University Patent Office) indicated marked advantages in increasing the water rates in a laboratory hydroseparator, thereby allowing more efficient desliming. The same device was shown to be effective in preventing the losses of fine, high-grade magnetite particles to the froth in cationic silica flotation using a Denver laboratory flotation cell. The device is simple in construction, low cost and may be installed readily in existing equipment, both in hydroseparators and flotation cells.

Certain layered clay-type silicate minerals commonly present in magnetic taconite, such as minnesotaite, stilpnomelane and greenalite, adsorb excessive amounts of amine collectors by cationic exchange reaction, which may be responsible for the adverse effect on flotation results. In addition, the presence of the layered clay-type minerals in slime fractions with adsorbed collectors appears to be responsible for forming persistent flotation froths. Thorough desliming ahead of flotation in a hydroseparator using this device will cut down the amount of slimes in flotation and, hence, the reagent dosage, thereby alleviating the overly stable froth problem observed in certain plants. Furthermore, the use of the device in flotation cells will not only help prevent excessive losses of iron units in the form of fine, high-grade magnetite, but is also expected to improve balling by keeping more fines in the final concentrates.

In this report, characteristic features of the magnetic field distribution device are described, and the results of a few flotation tests using a 50-cu.ft. WEMCO flotation cell modified into a batch unit for investigating the effect of magnetic field strengths are reported.

MAGNETIC FIELD DISTRIBUTION DEVICE

Design characteristics of the magnetic field distribution device in the form of gridwork were described in Progress Report No.1 (2000) and summarized in an accompanying Final Report titled, "Magnetic Field Application in Hydroseparators" (2001). It was concluded that the field strengths at the centers of the middle squares in nine square frame gridworks gave essentially the same readings with multi-opening gridworks beyond nine squares. In the present investigation using a 50-cu.ft. WEMCO flotation cell with an inside dimension of 50 inch by 67.5 inch, a gridwork having 8-inch openings with 1-inch wide magnetic sheet strips would give a sufficient number of openings with sufficient field strengths.

An attempt was made to study how large an opening may be made for plant applications. Nine-opening square frames of 1-inch magnetic strips with 8-, 10-, 12- and 18-inch openings were constructed, and field strengths at the centers of the center squares were measured as a function of the number of layers. The results are plotted in Figure 1. Field strengths show linear dependence on opening size on a log-log plot, from which may be determined the number of layers of 1-inch strips required to achieve

given field strengths. As previous reports indicated, higher field strengths may be attained by using wider strips, more layers and/or stronger magnetic strips.

FLOTATION TEST SETUP

A standard 50-cu.ft. WEMCO flotation cell was modified for use as a batch flotation cell. The test procedure was chosen to follow that developed by Wu et al. (1995), except for the magnetic gridwork in applying the magnetic field.

Figure 2 shows the initial design of the gridwork arrangement of 8-inch openings inside the flotation cell, which was later modified to have one less row of openings for ease of construction using L-shaped angle iron for structural strength. An example of field strength readings of each opening with 6 layers of magnetic sheets in the initial design is included in the figure. The side openings had much higher readings than those in the center rows, but the center 4 rows were about the same. As magnetite particles will be less likely to go through the side openings, the field strength readings of the 28 center row 8-inch openings were averaged and plotted as a function of the number of layers of magnetic sheets in Figure 3. Though the standard deviations are relatively large, the average values are linearly dependent on the number of layers.

The magnetic gridwork was installed at 6 inches below the overflow lip, so that the froth/pulp interface will be located at the half way point of the 8 layers of ¼-inch thick magnetic sheets with 5 inches of froth height, as mentioned by Wu et al. (1995). Figure 4 shows the gridwork with 8 layers of magnetic sheet strips. The pulp level was controlled by an addition of tap water by observing a rod attached to an air bulb, floating at the froth/pulp interface and the rod showing the 5-inch level mark.

FLOTATION TEST PROCEDURE

A plant flotation feed sample, dated February 5, 2001, was received in ten 55-gallon drums with a net weight of approximately 5,000 lbs. from the U.S. Steel Minntac plant. The head and screen analyses data are given in Table 1. For flotation tests, three drums of the sample were pulped in a 400-gallon sump at 40% solids. Then, to the flotation cell, 80 gallons of tap water was added, the rotor was turned on, and the 40% solid pulp was added to the level of 220 gallons. This volume of pulp was noted to give 5 inches of froth height in the preliminary test (Test No. 1). Pulp density in the flotation cell was about 25%. Test No. 1 was performed without magnetic sheets. Test No. 2 was performed with 8 layers of magnetic sheets.

With magnetic sheet strips on the gridwork, a large amount of magnetite coats the gridwork. A typical example of gridwork with 8 layers of magnetic strips after a test is shown in Figure 5. The amount of magnetite attached to the grid work was estimated by assuming that the amount of magnetite attached per cm^2 of the gridwork is the same as that on the gridwork in the hydroseparator tests (10 g/cm^2). When the gridwork had 8 layers of magnetic sheets, the amount of magnetite on the gridwork was estimated at 12% of the solids in the flotation cell. In an attempt to compensate for this loss of the sample, the final concentrate remaining in the cell of a previous test was used to coat the grid work, then the final concentrate was completely flushed out, and a new sample was introduced into the cell as described above. A well-mixed pulp sample was taken,

% solids determined, and the head weight of solids was estimated, which ranged from 245 to 265 kg.

Collector and frother levels were fixed at 0.2 lb/LT MG-82 and at 0.03 lb/LT MIBC, which were added as 1% and 0.07% water emulsions, respectively, into the pulp while the rotor was stopped momentarily. The rotor was started, then a pulp sample deep in the cell was taken for amine analysis after 45 seconds of conditioning, and air was turned on at 60 seconds of conditioning. The froth product overflowed into the froth launder was collected into 55-gallon drums at time intervals of 0.5, 1.0, 1.5, 2.5, 3.5 and 5.0 minutes. The froth products were filtered, dried, weighed and analyzed for iron and silica. During the flotation, both froth and cell pulp samples were taken at 0.5, 1.5 and 5.0 minutes for amine analyses. The final concentrate sample remaining in the cell was also sampled, the solution analyzed for residual amine, and the solids for iron and silica.

RESULTS AND DISCUSSIONS

A total of 6 tests were performed; first without a magnetic field in order to become familiarized with the procedure, then a test with 8 layers of magnetic sheets, followed by a test with 6 layers to see if magnetic field application had the intended effect. Another test without magnetic sheets was made in order to establish the baseline data for comparison with the tests with the magnetic field imposed. Having confirmed the effect, tests with 4 and then 2 layers of magnetic sheets were carried out to ascertain how the field strengths affected the flotation results. Table 2 summarizes the results obtained.

Reproducibility of the results of Test No. 4 and Test No. 1, the latter being preliminary, was not particularly good, so the results of Test No. 1 were eliminated from further analyses in this report. It is evident that in all cases, the flotation was essentially completed in about 3 minutes. Final concentrates after 5 minutes of flotation were all analyzed 3.5% SiO_2 or less, yet the weight recoveries are seen to decrease with an increasing number of magnetic sheets, clearly indicating the effectiveness of a magnetic field in depressing magnetic particles.

In an attempt to see if this depressant action was selective, the test results were plotted in the form of grade-recovery curves in Figure 6. It is apparent that the selectivity of separation increased with an increasing number of magnetic sheets to 6 layers. The results of 6 and 8 layers indicate that an increase in the number of layers beyond 6 layers may not improve the selectivity any further. In fact, 8 layers of magnetic sheets (96 gauss) depressed the sample without improving the selectivity of separation relative to 6 layers of magnetic sheets (74 gauss), leading to increased silica in the final concentrate.

Size analyses of the froth products and final concentrates of Tests No. 2 to 6 were made, and the distributions of iron and silica units in different size fractions were calculated. Detailed calculation results are given in the Appendix. The composited head analyses of iron and silica from all the size fractions are both within a few tenths of a percent, indicating that the material balances of the results are satisfactory.

To indicate the size fraction(s) where major iron losses occurred, relevant results were extracted from the Appendix and listed in Table 3. Iron losses to different size fractions of total froths expressed as percentages of the total iron units in the feed sample are plotted as a bar graph in Figure 7. It is apparent that the major losses

occurred in the –500 mesh fraction and the magnetic field had a profound influence in depressing this size fraction. Figure 8 shows the manner in which the –500 mesh fraction increased with flotation time according to the different number of layers of magnetic sheets. Iron losses to froth products are seen to level off after 3 minutes. As mentioned previously, lack of flotation was responsible for this behavior.

Optimum flotation results are obtained at optimum aeration rates, expressed as ft^3 of air per ft^2 of froth surface per minute (Arbiter, 1962). The presence of a gridwork restricts the apparent escape velocity of particle-bubble aggregates through the gridwork and adversely affects the aggregate stability. Magnetite coating of ½ inch on the gridwork further narrows the openings. In fact, a 1-inch wide gridwork reduces the flotation area by 20%, and with a ½-inch thick magnetite coating on the grid, the area would be further reduced by an additional 20%, totalling as high as 40%. In order to maintain the same aeration rate through the gridwork openings, air flow rates need to be reduced by 40% in order to avoid increased turbulence on particle-bubble aggregates. As flotation rates are proportional to aeration, the capacity will be reduced by this amount. Alternatively, the turbulence may loosen the flocs and occluded middling particles may be released. It becomes of interest, therefore, to reduce the amount of magnetite coating in some manner, so that the effect of aeration rate on the metallurgical results may be assessed.

Table 4 shows the % solids and residual amine analyses of froths and cell pulps. Initially, a test was carried out with water only in the flotation cell with exactly the same procedure as in the presence of a magnetic taconite sample. As flotation progressed, the amine concentration decreased, partly by its surface activity and perhaps more importantly by the addition of dilution water to maintain the level of the froth/pulp interface. Amine concentrations of froths in the "water only" case are noted to be an order of magnitude higher than in the cell due to its surface activity. Amine concentrations after conditioning are particularly interesting because the difference between the "water only" case and in the presence of solids gives the amount of adsorption onto the magnetic taconite sample. Concentrations after conditioning in all cases ranged 3 to 4 ppm as compared to 22 ppm in the "water only" case, which means 80 to 85% of the amine added was adsorbed on the flotation feed sample. Amine concentrations in the froths were higher than those in the cell, but the differences were not as pronounced as in the case of "water only." The froths were quite watery, often less than 10% solids. Also, perhaps the residual amine might have continued to adsorb on siliceous gangue-rich froth products before the solids were removed by filtration. Amine concentrations in the froth products at 5 minutes were appreciably higher because the flotation was essentially complete after 3 minutes, and the lingering froths were quite dry due to very little froth overflow.

CONCLUSIONS

1. Application of a magnetic field in the form of gridwork with magnetic sheet strips depressed magnetic particles, thereby improving iron recoveries.

2. Magnetite particles coated the gridwork to a thickness of about ½ inch, but the coating did not interfere with flotation.

3. Iron recoveries to the cell product increased with increasing number of magnetic sheets.

4. Test results expressed in the form of grade-recovery curves clearly indicated that the selectivity of separation improved with an increase in the field strength to 74 gauss (6 layers), but further increase to 96 gauss (8 layers) simply decreased the weight recovery into the cell product without improving the selectivity.

5. Major losses of iron units in froth products were in the –500 mesh fraction, and the application of a magnetic field decreased the flotation of fine magnetite particles, thereby improving the selectivity of separation.

6. Amine adsorption in the conditioning step amounted to 80 to 85%.

7. The use of a 9-opening square grid was shown to provide a useful guide in designing the gridwork suitable for estimating the magnetic field necessary in larger commercial flotation cells.

REFERENCES

Arbiter, N., and Harris, C. C., 1962, Flotation machines, in *Froth Flotation, 50th Anniversary Volume,* SME/AIME, pp. 347-364

Iwasaki, I., and Ersayin, S., 2001, Magnetic field application in hydroseparators, Final Report, Coleraine Minerals Research Laboratory, Natural Resources Research Institute, University of Minnesota-Duluth, CMRL/TR-01-03, NRRI/TR-2001/13, 35p.

Iwasaki, I., and Wu, C., 2000, Magnetic field application in hydroseparators and flotation cells, Progress Report No. 1, Coleraine Minerals Research Laboratory, Natural Resources Research Institute, University of Minnesota-Duluth, CMRL/TR-0012, NRRI/TR-2000/38, 21p.

Seetharama, V.N., Malicsi, A.S., Iwasaki, I., 1991, Effect of magnetic fields in the flotation of magnetic concentrates, in *Investigation into Production of Iron Ore Concentrates with Less Than 3 Percent Silica from Minnesota Taconites,* Final Report to the State of Minnesota and the American Iron and Steel Institute, Mineral Resources Research Center, University of Minnesota, Minneapolis, Minnesota, 30p.

Sonolikar, R.L., Mandlekar, V.A., and Gaidhani, S.B., 1988, Effect of magnetic field on column flotation of ore containing magnetic content, in *Column Flotation '88,* K.V.S. Sastry, Ed., SME Annual Meeting, Phoenix, AZ, January 25-28, 1988.

Wu, C., Benner, B., and Bleifuss, R.L., 1995, The flotation of taconite in a magnetic field, *Proceedings, Minnesota Section SME 68th Annual Meeting,* Center for Professional Development, University of Minnesota-Duluth, Duluth, Minnesota, pp. 245-256.

Table 1. Head and Screen Analysis Data on Minntac Plant Flotation Feed Sample (02-05-01) Used in Flotation Tests

(a) Head analysis results

% Fe	% SiO_2
67.8	5.47

(b) Screen analysis results

Size, mesh	% Weight	% Fe	% Mag Fe
150	0.6	36.3	40.94
200	2.2	39.7	35.73
270	11.1	58.4	14.71
400	14.9	66.6	6.01
500	24.7	70.2	3.06
-500	46.5	69.8	2.76
Composite	100.0	67.3	5.60

Table 2. Effect of magnetic field on batch flotation tests

Sample min	%wt	%Fe	$\%SiO_2$	Cum %Wt	Cum % Fe	Cum Fe Rec	Cum $\%SiO_2$
Flotation Test No. 1 (no mag sheet)							
0.5	10.68	63.3	11.67	100.00	67.7	100.0	5.87
1.0	7.55	65.8	9.60	89.32	68.2	90.0	5.17
1.5	7.28	65.3	9.30	81.77	68.4	82.7	4.76
2.5	10.74	66.1	7.45	74.49	68.7	75.6	4.32
3.5	0.70	64.8	9.01	63.75	69.1	65.1	3.79
5.0	0.18	64.3	9.30	63.05	69.2	64.5	3.74
Final conc	62.87	69.2	3.72	62.87	69.2	64.3	3.72
Composite	100.00						
Flotation Test No. 2 (8 layers)							
0.5	4.28	52.8	21.81	100.0	67.6	100.0	5.12
1.0	2.84	57.7	17.00	95.72	68.2	96.7	4.38
1.5	2.94	60.8	12.15	92.88	68.5	94.2	3.99
2.5	3.58	64.2	8.27	89.94	68.8	91.6	3.72
3.5	0.09	59.3	13.17	86.36	69.0	88.2	3.54
5.0	0.05	59.4	13.60	86.27	69.0	88.1	3.53
Final conc	86.22	69.0	3.52	86.22	69.0	88.1	3.52
Composite	100.00						
Flotation Test No. 3 (6 layers)							
0.5	5.16	53.8	20.83	100.0	68.1	100.0	4.89
1.0	3.31	58.2	15.59	94.84	68.8	95.9	4.02
1.5	2.17	63.6	9.39	91.53	69.2	93.1	3.60
2.5	3.77	66.1	7.89	89.36	69.3	91.1	3.46
3.5	0.08	61.7	13.34	85.59	69.5	87.4	3.26
5.0	0.03	59.0	15.82	85.51	69.5	87.3	3.25
Final conc	85.48	69.5	3.25	85.48	69.5	87.3	3.25
Composite	100.00						

Table 2 (cont'd)

Flotation Test No. 4
(no mag sheet)

0.5	8.08	60.3	14.48	100.0	67.5	100.0	5.54
1.0	6.88	61.8	11.79	91.92	68.2	92.8	4.76
1.5	5.79	63.0	10.57	85.04	68.7	86.5	4.19
2.5	3.69	63.0	10.23	79.25	69.1	81.1	3.72
3.5	0.08	60.3	12.86	75.56	69.4	77.6	3.40
5.0	0.03	59.0	13.98	75.48	69.4	77.6	3.39
Final conc	75.45	69.4	3.39	75.45	69.4	77.5	3.39
Composite	100.00						

Flotation Test No. 5
(4 layers)

0.5	5.07	55.2	19.47	100.0	67.4	100.0	5.24
1.0	4.11	58.9	15.11	94.93	68.0	95.8	4.48
1.5	5.26	63.3	9.84	90.82	68.4	92.3	4.00
2.5	6.47	64.8	7.90	85.56	68.8	87.3	3.65
3.5	0.11	59.5	13.54	79.09	69.1	81.1	3.30
5.0	0.02	58.8	14.37	78.98	69.1	81.0	3.28
Final conc	78.96	69.1	3.28	78.96	69.1	81.0	3.28
Composite	100.00						

Flotation Test No. 6
(2 layers)

0.5	7.66	58.0	16.53	100.00	67.5	100.0	5.35
1.0	5.89	60.9	12.67	92.34	68.3	93.4	4.42
1.5	5.72	64.2	9.35	86.45	68.8	88.1	3.86
2.5	5.96	64.0	8.03	80.73	69.1	82.7	3.47
3.5	0.09	60.6	11.52	74.77	69.5	77.0	3.11
5.0	0.01	61.2	11.85	74.68	69.5	76.9	3.10
Final conc	74.67	69.5	3.1	74.67	69.5	76.9	3.10
Composite	100.00						

Table 3. Effect of Magnetic Field on Iron Losses to Size Fraction in Flotation

Mag grid		Flotation	Cum	Fe Losses to Froth							Total
Layers	Gauss	Time, min	% Wt.	100 mesh	150 mesh	200 mesh	270 mesh	400 mesh	500 mesh	-500 mesh	Fe Loss
0	0	0.5	8.08		0.06	0.22	0.93	1.12	0.72	4.99	8.03
		1.0	14.69		0.11	0.33	1.51	2.07	1.76	9.33	15.10
		1.5	20.75		0.14	0.41	1.97	2.88	2.65	13.04	21.09
		2.5	24.44	0.01	0.15	0.48	2.30	3.42	3.06	15.52	24.94
		3.5	24.52	0.02	0.15	0.48	2.31	3.43	3.07	15.57	25.02
		5.0	24.55	0.02	0.15	0.48	2.31	3.43	3.08	15.58	25.04
8	96	0.5	4.28	0.09	0.03	0.06	0.28	0.29	0.32	2.21	3.29
		1.0	7.12	0.09	0.05	0.11	0.53	0.57	0.60	3.68	5.63
		1.5	10.06	0.09	0.06	0.16	0.84	0.99	0.98	5.15	8.26
		2.5	13.64	0.09	0.07	0.21	1.35	1.62	1.37	6.96	11.68
		3.5	13.73	0.10	0.07	0.22	1.35	1.63	1.38	7.00	11.76
		5.0	13.78	0.11	0.08	0.22	1.36	1.64	1.38	7.03	11.80
6	74	0.5	5.50	0.03	0.03	0.09	0.40	0.40	0.54	2.59	4.42
		1.0	9.03	0.05	0.05	0.20	0.79	0.78	0.84	4.75	7.46
		1.5	11.35	0.06	0.07	0.25	1.07	1.08	1.05	6.03	9.62
		2.5	15.37	0.08	0.09	0.31	1.41	1.55	1.59	8.39	13.41
		3.5	15.45	0.08	0.09	0.31	1.42	1.55	1.59	8.43	13.48
		5.0	15.48	0.08	0.10	0.31	1.42	1.56	1.60	8.45	13.50
4	49	0.5	5.07								
		1.0	9.18								
		1.5	14.44								
		2.5	20.91								
		3.5	21.02								
		5.0	21.04								
2	23	0.5	7.6								
		1.0	13.55								
		1.5	19.27								
		2.5	25.23								
		3.5	25.32								
		5.0	25.33								

Table 4. Percent Solids and Amine Concentrations of Froths and Cell Pulps in Flotation

(a) Percent Solids

Sample	% Solids						
	Water Only	Test 1	Test 2	Test 3	Test 4	Test 5	Test 6
Froth							
0.5 min		18.2	7.1	8.2	13.7	9.6	14.1
1.5 min		15.3	9.1	—	6.6	11.9	9.7
5.0 min*		19.0	25.5	15.6	14.0	20.8	17.7
Cell Pulp							
After condition**		21.2	22.1	21.7	20.6	23.4	24.7
0.5 min		22.2	23.0	22.2	20.7	24.7	23.2
1.5 min		20.3	—	19.5	17.4	23.5	21.8
5.0 min		10.1	—	10.9	9.7	10.5	11.4
Final Conc.		13.1	—	16.3	11.4	18.0	16.0

(b) Amine Concentrations

Sample	Amine Concentration, ppm						
	Water Only	Test 1	Test 2	Test 3	Test 4	Test 5	Test 6
Froth							
0.5 min	110	13.5	7.1	5.4	4.1	4.3	4.7
1.5 min	81	8.4	9.1	—	3.8	3.0	4.3
5.0 min*	197	24	25.5	26.5	28.1	12.9	21.4
Cell Pulp							
After condition**	22	4.3	2.9	4.0	3.5	3.4	3.2
0.5 min	18	4.2	2.6	2.7	2.3	2.1	2.1
1.5 min	13	2.0	—	1.1	1.1	1.0	0.8
5.0 min	5	0.7	—	0.6	0.5	0.6	0.6
Final Conc.	4	0.9	0.03	0.6	0.4	0.6	0.4

* Dry froths due to very little froth overflow.
** After 45 seconds of conditioning. Some solids settled out while sampling.

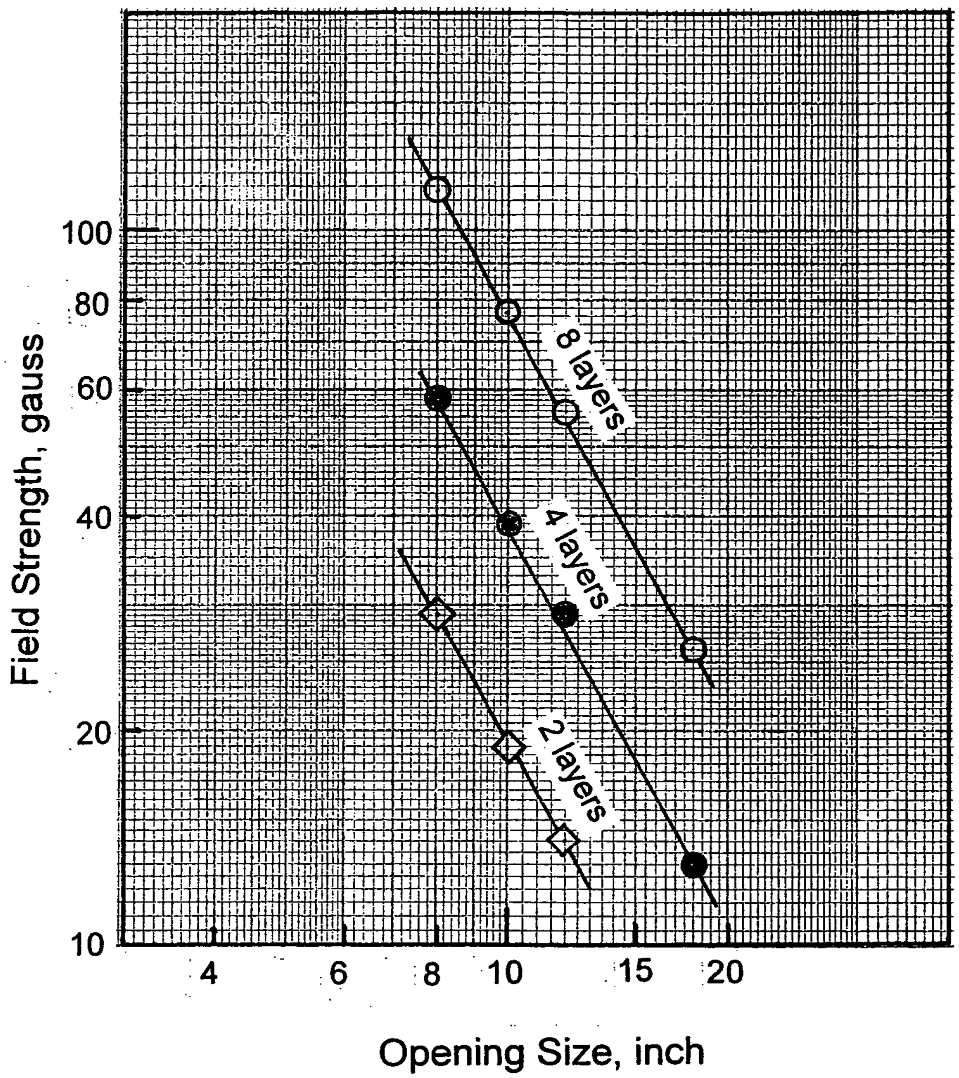

Figure 1. Field strengths of center squares of 9-square frames as functions of opening size and number of layers of 1-inch strips.

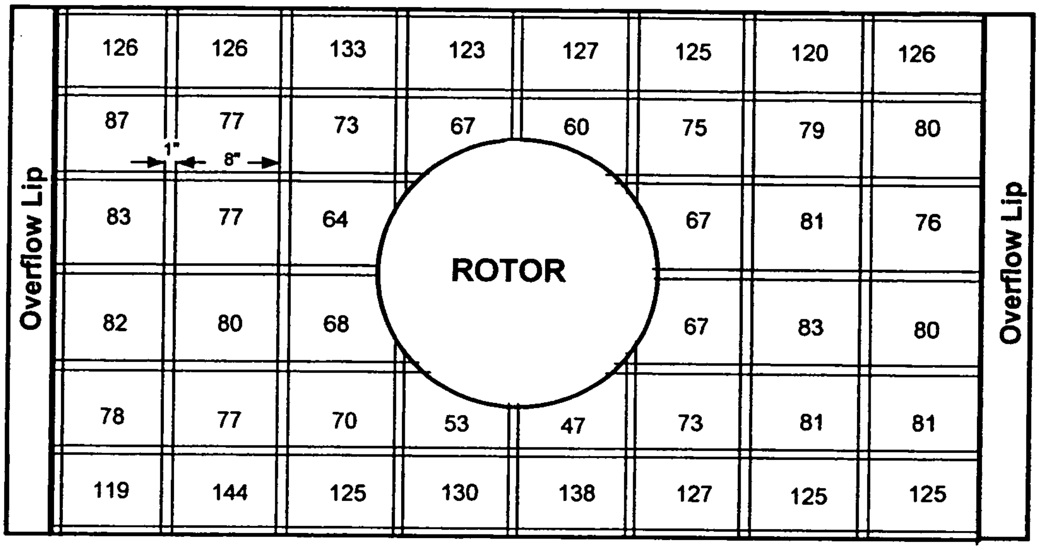

Figure 2. Initial gridwork frame of 1-inch width magnetic sheets with 8-inch openings fabricated to fit inside a 50-cubic foot WEMCO flotation cell. The numbers in openings indicate typical values of field strengths of a gridwork with 6 layers of magnetic sheets.

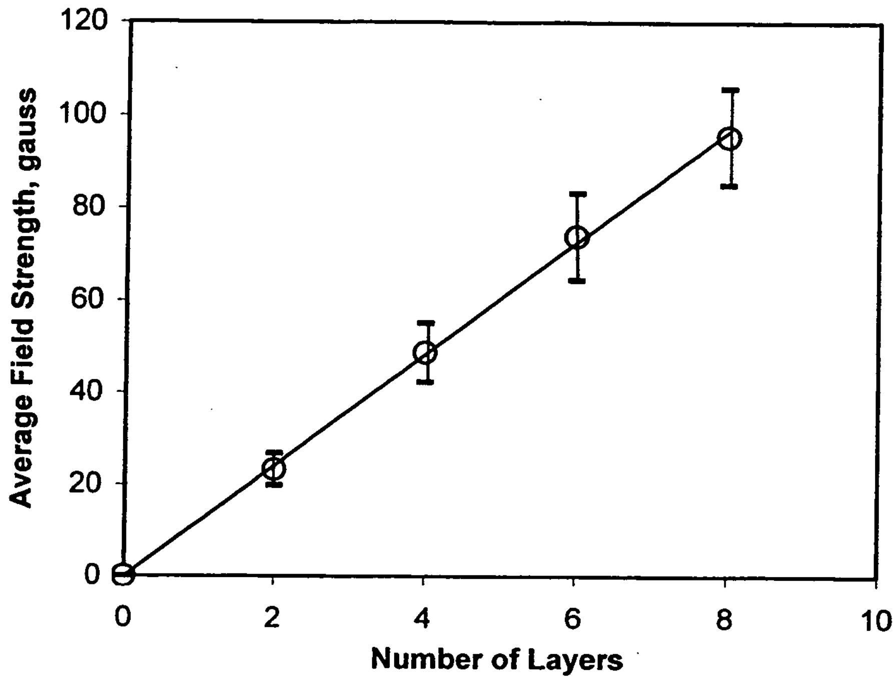

Figure 3. Average field strengths of 28 center row 8-inch openings inside flotation cell as a function of the number of layers of magnetic sheets.

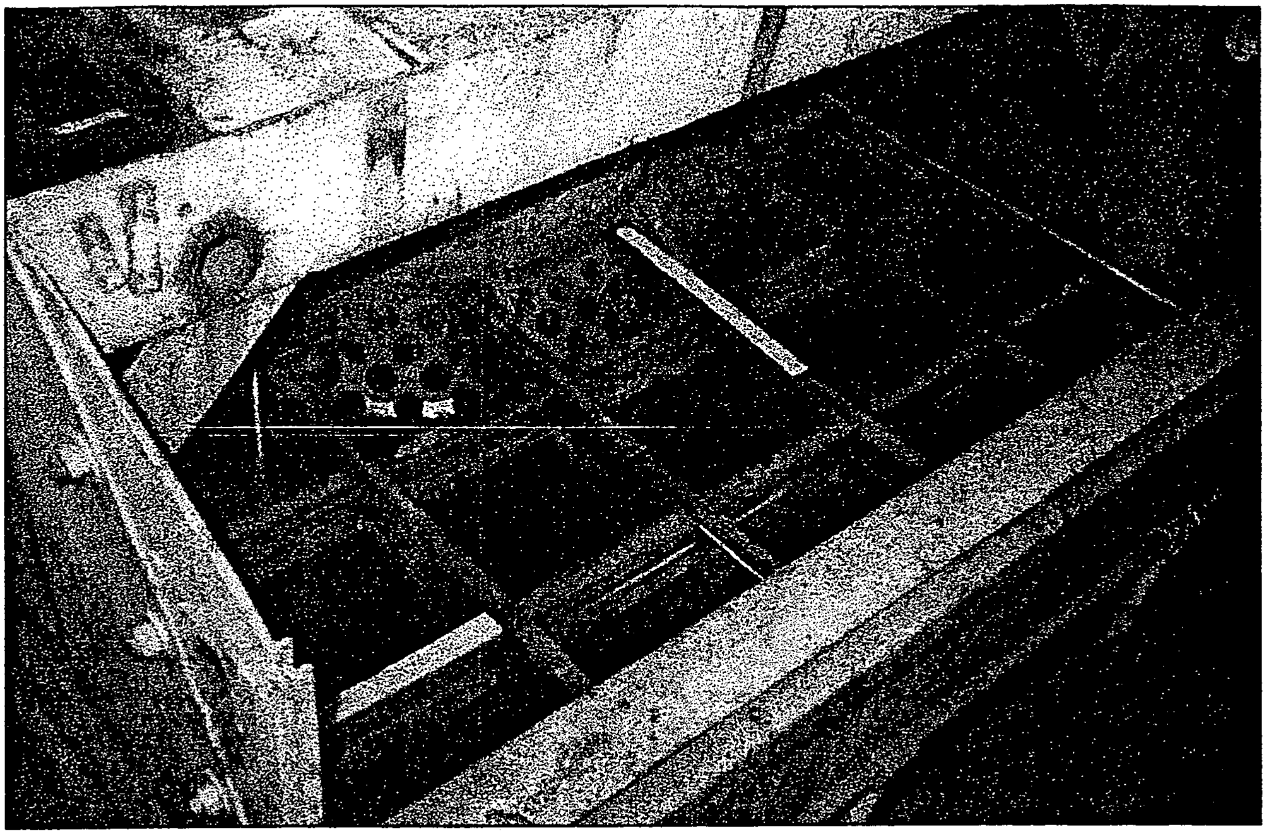

Figure 4. Gridwork Inside Flotation Cell

Figure 5. Gridwork Coated with Magnetite After Test

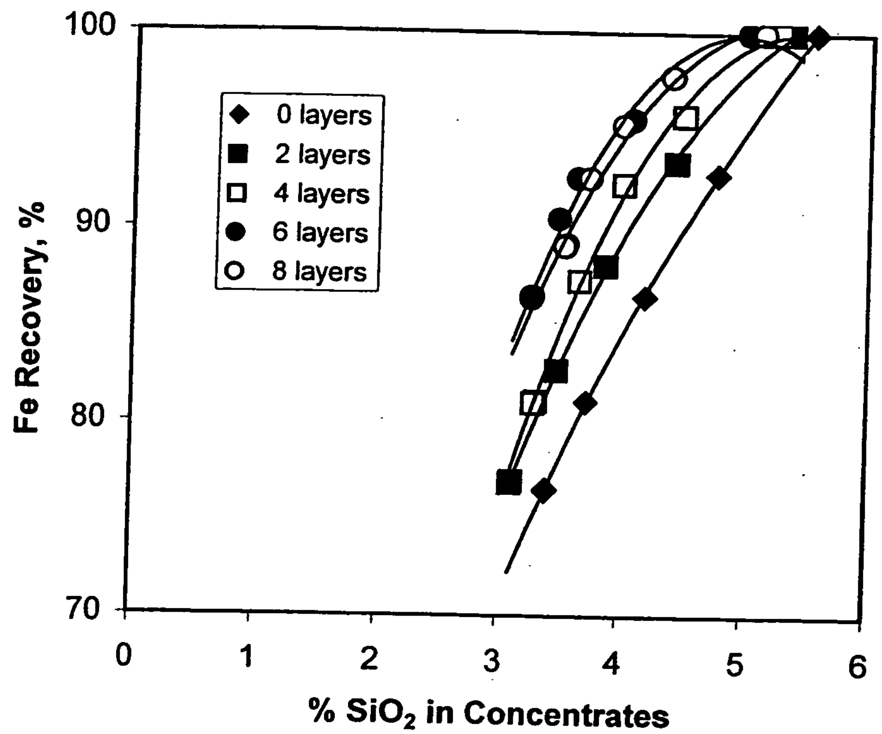

Figure 6. Grade-recovery plots showing the effect of magnetic field on batch flotation tests.

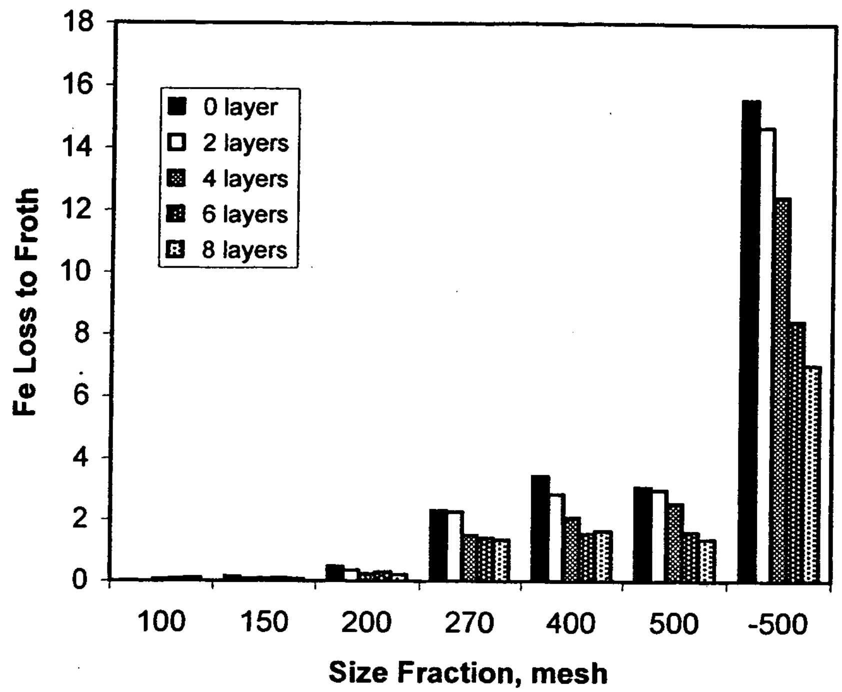

Figure 7. Iron losses to different size fractions of total froths expressed as percentages of the total iron units in feed sample

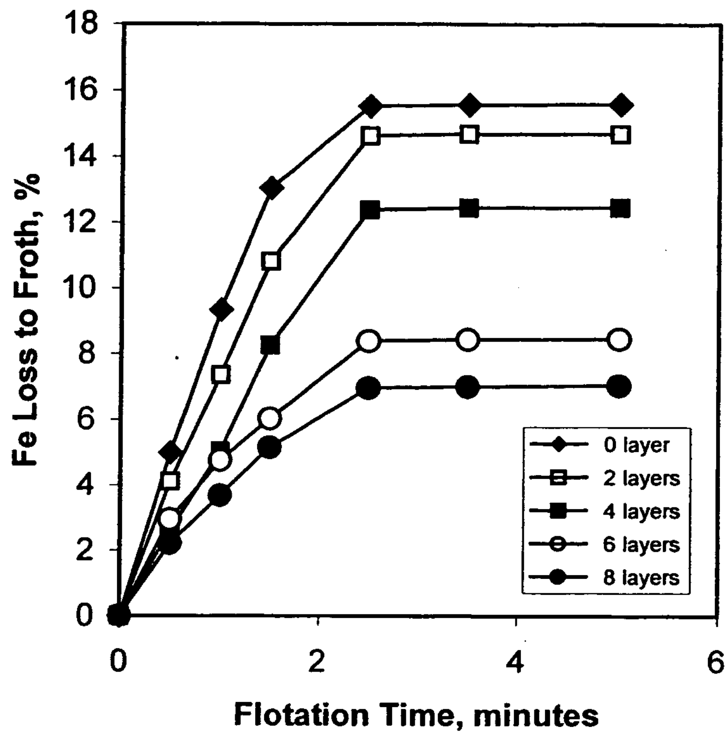

Figure 8. Cumulative iron losses of -500 mesh fractions of froths as a function of flotation time

APPENDIX

Effect of Magnetic Field on Size Fractions in Flotation

Legend:

%wt = % weight of size fractions in that particular product totaling 100%

%wt (overall) = % weight of size fractions in total sample
= (%wt)*(%wt of product in total sample) / 100

Unit Fe = (% Fe)*(%wt (overall)) / 100

Unit SiO_2 = (%SiO_2)*(%wt (overall)) / 100

Fe recovery = Iron recovery in size fraction over total sample

SiO_2 recovery = Silica recovery in size fraction over total sample

Fe loss to size = Iron loss in size fraction over total sample

Magnetic Field Flotation Size Analyses

Flotation test No. 2 (mag sheet 8 layers)

Products	100 mesh	150mesh	200 mesh	270 mesh	400 mesh	500 mesh	-500 mesh	sum
0.5 min froth								
%wt	2.8	1.2	3.5	12.9	10.9	10.4	58.3	100
%wt(overall)	0.11984	0.05136	0.1498	0.55212	0.46652	0.44512	2.49524	4.28
%Fe	51.5	35.6	27.2	34.6	42.6	48.9	60.1	52.0519
%SiO2	23.57	45.14	55.49	45.49	25	26.25	12.72	21.88276
Unit Fe	0.061718	0.018284	0.040746	0.191034	0.198738	0.217664	1.499639	2.227821
Unit SiO2	0.028246	0.023184	0.083124	0.251159	0.11663	0.116844	0.317395	0.936582
Fe recovery	86.26638	9.493933	3.862385	3.103608	2.042323	1.834604	3.870204	3.285005
SiO2 recovery	92.33593	8.893516	9.456332	16.38206	14.40638	22.03459	24.74667	17.58555
Fe loss to size	0.091005	0.026961	0.060081	0.281686	0.293046	0.320953	2.211274	3.285005
Cumulative conc								
%wt(overall)	0.01675	0.52333	2.39234	9.84279	14.10375	16.5482	52.29284	95.72
Unit Fe	0.009825	0.174304	1.014188	5.964175	9.532217	11.64668	37.24868	65.59007
Unit SiO2	0.002345	0.237499	0.795906	1.281978	0.692942	0.413431	0.96518	4.389281
%Fe	58.6594	33.30665	42.39315	60.59435	67.5864	70.38032	71.23094	68.52285
%SiO2	13.99701	45.38232	33.26894	13.02454	4.913175	2.498346	1.845721	4.585542
Fe recovery	13.73362	90.50607	96.13762	96.89639	97.95768	98.1654	96.1298	96.71499
SiO2 recovery	7.664072	91.10648	90.54367	83.61794	85.59362	77.96541	75.25333	82.41445
1 min froth								
%wt		1.3	4.2	14.2	12.9	11.4	56	100
%wt(overall)		0.03692	0.11928	0.40328	0.36636	0.32376	1.5904	2.84
%Fe		35.1	30.4	41.2	51.5	58.3	62.4	55.8172
%SiO2		43.09	49.14	35.2	23.29	16.29	9.09	17.57432
Unit Fe		0.012959	0.036261	0.166151	0.188675	0.188752	0.99241	1.585208
Unit SiO2		0.015909	0.058614	0.141955	0.085325	0.052741	0.144567	0.499111
Cumulative froth								
%wt(overall)	0.11984	0.08828	0.26908	0.9554	0.83288	0.76888	4.08564	7.12
Unit Fe	0.061718	0.031243	0.077007	0.357185	0.387413	0.406416	2.492049	3.81303
Unit SiO2	0.028246	0.039093	0.141738	0.393114	0.201955	0.169585	0.461962	1.435693
%Fe	51.5	35.39089	28.61852	37.3859	46.51485	52.85815	60.99531	53.55379
%SiO2	23.57	44.28266	52.67512	41.14653	24.24782	22.05604	11.30697	20.16422
Fe recovery	86.26638	16.22277	7.299673	5.80297	3.981243	3.425524	6.431372	5.622454
SiO2 recovery	92.33593	14.99626	16.12438	25.64115	24.94593	31.98046	36.01833	26.957
Fe loss to size	0.091005	0.046069	0.113549	0.526682	0.571255	0.599275	3.674619	5.622454
Cumulative conc								
%wt(overall)	0.01675	0.48641	2.27306	9.43951	13.73739	16.22444	50.70244	92.88
Unit Fe	0.009825	0.161345	0.977927	5.798023	9.343541	11.45792	36.25627	64.00486
Unit SiO2	0.002345	0.22159	0.737292	1.140023	0.607617	0.360691	0.820613	3.890171
%Fe	58.6594	33.17053	43.02249	61.42293	68.0154	70.62138	71.50795	68.91135
%SiO2	13.99701	45.55632	32.4361	12.07714	4.423087	2.223133	1.618488	4.188383
Fe recovery	13.73362	83.77723	92.70033	94.19703	96.01876	96.57448	93.56863	94.37755
SiO2 recovery	7.664072	85.00374	83.87562	74.35885	75.05407	68.01954	63.98167	73.043

1.5 min froth

%wt		0.9	3.5	15.2	16.1	13.2	51.1	100
%wt(overall)		0.02646	0.1029	0.44688	0.47334	0.38808	1.50234	2.94
%Fe		31.2	31.7	47.5	59.6	65.8	66.3	60.7708
%SiO2		46.91	48.02	28.37	14.4	7.76	6.27	12.96182
Unit Fe		0.008256	0.032619	0.212268	0.282111	0.255357	0.996051	1.786662
Unit SiO2		0.012412	0.049413	0.12678	0.068161	0.030115	0.094197	0.381078

Cumulative froth

%wt(overall)	0.11984	0.11474	0.37198	1.40228	1.30622	1.15696	5.58798	10.06
Unit Fe	0.061718	0.039499	0.109626	0.569453	0.669524	0.661772	3.4881	5.599691
Unit SiO2	0.028246	0.051505	0.191151	0.519894	0.270116	0.1997	0.556159	1.81677
%Fe	51.5	34.42444	29.47094	40.60907	51.25657	57.19925	62.42149	55.66294
%SiO2	23.57	44.88855	51.38738	37.07489	20.67923	17.26071	9.952767	18.05935
Fe recovery	86.26638	20.50939	10.39174	9.251562	6.880349	5.577828	9.001939	8.256953
SiO2 recovery	92.33593	19.75774	21.74564	33.91045	33.36531	37.65959	43.36267	34.11222
Fe loss to size	0.091005	0.058242	0.161648	0.839679	0.987237	0.975808	5.143334	8.256953

Cumulative conc

%wt(overall)	0.01675	0.45995	2.17016	8.99263	13.26405	15.83636	49.2001	89.94
Unit Fe	0.009825	0.153089	0.945308	5.585755	9.061431	11.20257	35.26022	62.2182
Unit SiO2	0.002345	0.209178	0.687879	1.013243	0.539456	0.330576	0.726416	3.509093
%Fe	58.6594	33.28389	43.55936	62.11481	68.31572	70.73953	71.66697	69.17745
%SiO2	13.99701	45.47844	31.69718	11.26749	4.067051	2.087448	1.476452	3.901593
Fe recovery	13.73362	79.49061	89.60826	90.74844	93.11965	94.42217	90.99806	91.74305
SiO2 recovery	7.664072	80.24226	78.25436	66.08955	66.63469	62.34041	56.63733	65.88778

2.5 min froth

%wt		0.7	2.7	17.1	18.5	10.9	50.1	100
%wt(overall)		0.02506	0.09666	0.61218	0.6623	0.39022	1.79358	3.58
%Fe		38.5	36.4	56	65	68.6	68.5	64.6492
%SiO2		38.19	42.1	18.45	7.56	4.1	4.25	8.53373
Unit Fe		0.009648	0.035184	0.342821	0.430495	0.267691	1.228602	2.314441
Unit SiO2		0.00957	0.040694	0.112947	0.05007	0.015999	0.076227	0.305508

Cumulative froth

%wt(overall)	0.11984	0.1398	0.46864	2.01446	1.96852	1.54718	7.38156	13.64
Unit Fe	0.061718	0.049147	0.14481	0.912274	1.100019	0.929463	4.716703	7.914133
Unit SiO2	0.028246	0.061076	0.231845	0.632841	0.320186	0.215699	0.632386	2.122278
%Fe	51.5	35.15501	30.90011	45.28626	55.88049	60.07467	63.89845	58.0215
%SiO2	23.57	43.68779	49.4718	31.41492	16.26532	13.9414	8.567102	15.55922
Fe recovery	86.26638	25.51911	13.72695	14.82117	11.30432	7.834093	12.17266	11.66968
SiO2 recovery	92.33593	23.42902	26.37505	41.27752	39.55005	40.6767	49.30596	39.84852
Fe loss to size	0.091005	0.072469	0.213528	1.345181	1.622018	1.370528	6.954953	11.66968

Cumulative conc

%wt(overall)	0.01675	0.43489	2.0735	8.38045	12.60175	15.44614	47.40652	86.36
Unit Fe	0.009825	0.143441	0.910124	5.242935	8.630936	10.93488	34.03162	59.90376
Unit SiO2	0.002345	0.199608	0.647186	0.900296	0.489386	0.314577	0.650189	3.203585
%Fe	58.6594	32.98332	43.89311	62.56149	68.48998	70.79358	71.78679	69.36517
%SiO2	13.99701	45.89843	31.21223	10.74281	3.883475	2.036605	1.371518	3.709571
Fe recovery	13.73362	74.48089	86.27305	85.17883	88.69568	92.16591	87.82734	88.33032
SiO2 recovery	7.664072	76.57098	73.62495	58.72248	60.44995	59.3233	50.69404	60.15148

3.5 min froth

%wt	14.5	2.6	2.8	12.9	9.7	6.9	50.6	100
%wt(overall)	0.01305	0.00234	0.00252	0.01161	0.00873	0.00621	0.04554	0.09
%Fe	59.3	54.6	41.6	50.2	59.7	63.7	63	59.7229
%SiO2	13.5	18.59	35.63	25.41	14.56	9.44	9.15	13.40995
Unit Fe	0.007739	0.001278	0.001048	0.005828	0.005212	0.003956	0.02869	0.053751
Unit SiO2	0.001762	0.000435	0.000898	0.00295	0.001271	0.000586	0.004167	0.012069

Cumulative froth

%wt(overall)	0.13289	0.14214	0.47116	2.02607	1.97725	1.55339	7.4271	13.73
Unit Fe	0.069456	0.050424	0.145859	0.918102	1.10523	0.933419	4.745393	7.967883
Unit SiO2	0.030008	0.061511	0.232743	0.635791	0.321457	0.216285	0.636553	2.134347
%Fe	52.26597	35.47512	30.95734	45.31442	55.89735	60.08917	63.89294	58.03265
%SiO2	22.58111	43.27462	49.39777	31.38051	16.25779	13.9234	8.570676	15.54513
Fe recovery	97.08315	26.18251	13.82633	14.91585	11.35788	7.867434	12.2467	11.74894
SiO2 recovery	98.09501	23.5959	26.47719	41.46994	39.70705	40.78725	49.63085	40.07513
Fe loss to size	0.102416	0.074353	0.215074	1.353775	1.629703	1.376361	6.997258	11.74894

Cumulative conc

%wt(overall)	0.0037	0.43255	2.07098	8.36884	12.59302	15.43993	47.36098	86.27
Unit Fe	0.002087	0.142164	0.909075	5.237106	8.625724	10.93092	34.00293	59.85001
Unit SiO2	0.000583	0.199173	0.646288	0.897346	0.488115	0.313991	0.646022	3.191517
%Fe	56.4	32.86637	43.8959	62.57864	68.49607	70.79644	71.79524	69.37522
%SiO2	15.75	46.04616	31.20685	10.72247	3.876074	2.033627	1.364038	3.699451
Fe recovery	2.916845	73.81749	86.17367	85.08415	88.64212	92.13257	87.7533	88.25106
SiO2 recovery	1.904985	76.4041	73.52281	58.53006	60.29295	59.21275	50.36915	59.92487

5 min froth

%wt	7.4	2.9	3.4	11	9.8	13.1	52.4	100
%wt(overall)	0.0037	0.00145	0.0017	0.0055	0.0049	0.00655	0.0262	0.05
%Fe	56.4	52.6	38.9	30.1	58.4	62.4	63.2	57.347
%SiO2	15.75	21.12	39.55	29.68	19.48	10.58	8.66	14.22034
Unit Fe	0.002087	0.000763	0.000661	0.001656	0.002862	0.004087	0.016558	0.028674
Unit SiO2	0.000583	0.000306	0.000672	0.001632	0.000955	0.000693	0.002269	0.00711

Cumulative froth

%wt(overall)	0.13659	0.14359	0.47286	2.03157	1.98215	1.55994	7.4533	13.78
Unit Fe	0.071543	0.051187	0.14652	0.919757	1.108092	0.937506	4.761951	7.996557
Unit SiO2	0.030591	0.061817	0.233415	0.637424	0.322412	0.216978	0.638822	2.141457
%Fe	52.37796	35.64805	30.98589	45.27323	55.90354	60.09887	63.89051	58.03017
%SiO2	22.39607	43.05089	49.36236	31.37591	16.26576	13.90936	8.57099	15.54033
Fe recovery	100	26.57854	13.88901	14.94275	11.38729	7.901884	12.28944	11.79122
SiO2 recovery	100	23.71337	26.55368	41.57642	39.82496	40.91794	49.80775	40.20864
Fe loss to size	0.105493	0.075477	0.216049	1.356216	1.633923	1.382388	7.021674	11.79122

Final conc.

%wt	0.5	2.4	9.7	14.6	17.9	54.9	100
%wt(overall)	0.4311	2.06928	8.36334	12.58812	15.43338	47.33478	86.22
%Fe	32.8	43.9	62.6	68.5	70.8	71.8	69.3822
%SiO2	46.13	31.2	10.71	3.87	2.03	1.36	3.69335
Unit Fe	0.141401	0.908414	5.235451	8.622862	10.92683	33.98637	59.82133
Unit SiO2	0.198866	0.645615	0.895714	0.48716	0.313298	0.643753	3.184406
Fe recovery	73.42146	86.11099	85.05725	88.61271	92.09812	87.71056	88.20878
SiO2 recovery	76.28663	73.44632	58.42358	60.17504	59.08206	50.19225	59.79136

Composite

%wt(overall)	0.13659	0.57469	2.54214	10.39491	14.57027	16.99332	54.78808	100
Unit Fe	0.071543	0.192588	1.054934	6.155208	9.730954	11.86434	38.74832	67.81789
Unit SiO2	0.030591	0.260683	0.87903	1.533137	0.809572	0.530275	1.282575	5.325863
%Fe	52.37796	33.5116	41.49786	59.21368	66.78637	69.81767	70.724	67.81789
%SiO2	22.39607	45.36067	34.57836	14.74892	5.556328	3.120493	2.340974	5.325863

Magnetic Field Flotation Size Analyses

Flotation test No. 3 (mag sheet 6 layers)

Products	100 mesh	150mesh	200 mesh	270 mesh	400 mesh	500 mesh	-500 mesh	sum
0.5 min froth								
%wt	0.8	1.3	4.4	13.3	10.5	12.2	57.5	100
%wt(overall)	0.044	0.0715	0.242	0.7315	0.5775	0.671	3.1625	5.16
%Fe	40.7	24	25.5	36.8	46.5	54.5	63.1	58.05698
%SiO2	35.01	61.01	58.27	44.38	30.88	22.19	10.15	22.73063
Unit Fe	0.017908	0.01716	0.06171	0.269192	0.268538	0.365695	1.995538	2.99574
Unit SiO2	0.015404	0.043622	0.141013	0.32464	0.178332	0.148895	0.320994	1.1729
Fe recovery	21.09	1.821456	1.135857	4.878979	4.7151	3.045847	5.165836	4.376733
SiO2 recovery	8.248416	7.16581	13.14108	32.9426	33.87691	29.30021	26.60298	23.01952
Fe loss to size	0.026429	0.025325	0.091071	0.397273	0.396307	0.539692	2.945008	4.421104
Cumulative conc								
%wt(overall)	0.50008	1.99173	8.63606	8.01191	7.89163	16.30627	51.16232	94.84
Unit Fe	0.205516	0.924944	5.371193	5.248192	5.426728	11.64065	36.63398	65.4512
Unit SiO2	0.171351	0.565132	0.932059	0.660831	0.34808	0.359275	0.885614	3.922343
%Fe	41.09668	46.43921	62.19494	65.50488	68.76562	71.38759	71.60344	69.01224
%SiO2	34.26481	28.37392	10.79265	8.248109	4.410744	2.203295	1.73099	4.135748
Fe recovery	91.98476	98.17854	98.86414	95.12102	95.2849	96.95415	94.83416	95.62327
SiO2 recovery	91.75158	92.83419	86.85892	67.0574	66.12309	70.69979	73.39702	76.98048
1 min froth								
%wt	1	1.6	6.2	16.8	12.8	9.2	52.4	100
%wt(overall)	0.0353	0.05648	0.21886	0.59304	0.45184	0.32476	1.84972	3.31
%Fe	44.2	33.5	32.8	44.8	57	62.7	66.3	62.22142
%SiO2	31.85	50.63	48.98	37.22	18.13	11.58	6.26	18.22007
Unit Fe	0.015603	0.018921	0.071786	0.265682	0.257549	0.203625	1.226364	2.059529
Unit SiO2	0.011243	0.028596	0.107198	0.220729	0.081919	0.037607	0.115792	0.603084
Cumulative froth								
%wt(overall)	0.0793	0.12798	0.46086	1.32454	1.02934	0.99576	5.01222	8.47
Unit Fe	0.033511	0.036081	0.133496	0.534874	0.526086	0.56932	3.221902	5.055269
Unit SiO2	0.026647	0.072218	0.248211	0.545369	0.260251	0.186502	0.436786	1.775985
%Fe	42.25801	28.19253	28.96673	40.38186	51.10909	57.17437	64.28093	59.6844
%SiO2	33.60334	56.42911	53.85823	41.17423	25.28325	18.72962	8.714426	20.96794
Fe recovery	14.99864	3.829812	2.457178	9.69434	9.237256	4.741821	8.340518	7.385675
SiO2 recovery	14.2686	11.86325	23.13087	55.34098	49.43861	36.70072	36.19951	34.85574
Fe loss to size	0.049455	0.053248	0.197013	0.789365	0.776397	0.8402	4.754873	7.460551
Cumulative conc								
%wt(overall)	0.46478	1.93525	8.4172	7.41887	7.43979	15.98151	49.3126	91.53
Unit Fe	0.189914	0.906023	5.299407	4.98251	5.16918	11.43703	35.40761	63.39168
Unit SiO2	0.160108	0.536536	0.824862	0.440102	0.266161	0.321668	0.769822	3.319259
%Fe	40.86098	46.81684	62.95926	67.15996	69.48018	71.56413	71.80237	69.25781
%SiO2	34.44821	27.72438	9.799717	5.932191	3.577534	2.012751	1.561106	3.626416
Fe recovery	85.00136	96.17019	97.54282	90.30566	90.76274	95.25818	91.65948	92.61432
SiO2 recovery	85.7314	88.13675	76.86913	44.65902	50.56139	63.29928	63.80049	65.14426

1.5 min froth

%wt	0.7	1.5	4.2	15.5	13.9	9	55.2	100
%wt(overall)	0.01624	0.0348	0.09744	0.3596	0.32248	0.2088	1.28064	2.17
%Fe	51.4	39.9	37.5	53.4	63.9	67.2	67.7	67.4733
%SiO2	22.14	38.02	39.49	21.09	8.98	5.29	4.67	10.6431
Unit Fe	0.008347	0.013885	0.03654	0.192026	0.206065	0.140314	0.866993	1.464171
Unit SiO2	0.003596	0.013231	0.038479	0.07584	0.028959	0.011046	0.059806	0.230955

Cumulative froth

%wt(overall)	0.09554	0.16278	0.5583	1.68414	1.35182	1.20456	6.29286	10.64
Unit Fe	0.041858	0.049966	0.170036	0.7269	0.732151	0.709633	4.088895	6.51944
Unit SiO2	0.030243	0.085449	0.28669	0.621209	0.289209	0.197548	0.496592	2.00694
%Fe	43.81197	30.69542	30.45604	43.16151	54.16039	58.91223	64.97674	61.27293
%SiO2	31.65479	52.49351	51.35054	36.88582	21.39407	16.39998	7.891358	18.86222
Fe recovery	18.73474	5.303663	3.129746	13.17473	12.85543	5.910483	10.5849	9.524807
SiO2 recovery	16.19386	14.03669	26.71674	63.03676	54.93976	38.87431	41.15604	39.3885
Fe loss to size	0.061829	0.07374	0.250939	1.072757	1.080506	1.047274	6.034379	9.621369

Cumulative conc

%wt(overall)	0.44854	1.90045	8.31976	7.05927	7.11731	15.77271	48.03196	89.36
Unit Fe	0.181566	0.892138	5.262867	4.790483	4.963115	11.29671	34.54062	61.9275
Unit SiO2	0.156513	0.523305	0.786383	0.364262	0.237202	0.310622	0.710016	3.088303
%Fe	40.4794	46.94349	63.25743	67.86089	69.73302	71.6219	71.91175	69.30115
%SiO2	34.89385	27.53585	9.451988	5.160051	3.332752	1.969367	1.478216	3.456024
Fe recovery	81.26526	94.69634	96.87025	86.82527	87.14457	94.08952	89.4151	90.47519
SiO2 recovery	83.80614	85.96331	73.28326	36.96324	45.06024	61.12569	58.84396	60.6115

2.5 min froth

%wt	0.5	0.9	2.9	11.3	12.8	13.6	58	100
%wt(overall)	0.0201	0.03618	0.11658	0.45426	0.51456	0.54672	2.3316	3.77
%Fe	44.8	32.8	33.2	50.5	61.5	66.9	68.4	68.06372
%SiO2	26.38	45.87	45.55	24.33	11.48	5.64	3.85	9.686867
Unit Fe	0.009005	0.011867	0.038705	0.229401	0.316454	0.365756	1.594814	2.566002
Unit SiO2	0.005302	0.016596	0.053102	0.110521	0.059071	0.030835	0.089767	0.365195

Cumulative froth

%wt(overall)	0.11564	0.19896	0.67488	2.1384	1.86638	1.75128	8.62446	14.41
Unit Fe	0.050863	0.061833	0.208741	0.956302	1.048605	1.075389	5.68371	9.085442
Unit SiO2	0.035545	0.102045	0.339792	0.73173	0.348281	0.228383	0.586359	2.372135
%Fe	43.98371	31.07813	30.93004	44.72043	56.18392	61.40587	65.90221	63.04956
%SiO2	30.73795	51.28905	50.34855	34.21859	18.66076	13.0409	6.798788	16.46173
Fe recovery	22.7651	6.563295	3.842157	17.33252	18.41188	8.956836	14.71339	13.2737
SiO2 recovery	19.03307	16.76288	31.66535	74.25185	66.1613	44.94216	48.59562	46.55587
Fe loss to size	0.075063	0.091253	0.308059	1.411307	1.547529	1.587055	8.388001	13.40827

Cumulative conc

%wt(overall)	0.42844	1.86427	8.20318	6.60501	6.60275	15.22599	45.70036	85.59
Unit Fe	0.172562	0.880271	5.224162	4.561082	4.646661	10.93096	32.94581	59.3615
Unit SiO2	0.15121	0.506709	0.733281	0.25374	0.178131	0.279787	0.620249	2.723109
%Fe	40.27671	47.21798	63.6846	69.05489	70.37463	71.79145	72.09091	69.35565
%SiO2	35.29327	27.18004	8.938979	3.841636	2.697828	1.837565	1.357209	3.181573
Fe recovery	77.2349	93.43671	96.15784	82.66748	81.58812	91.04316	85.28661	86.7263
SiO2 recovery	80.96693	83.23712	68.33465	25.74815	33.8387	55.05784	51.40438	53.44413

3.5 min froth

%wt	7.3	4.2	3.9	10.2	8.8	10.2	55.4	100
%wt(overall)	0.00584	0.00336	0.00312	0.00816	0.00704	0.00816	0.04432	0.08
%Fe	60.3	54.9	38.1	46.2	54.7	61.7	65	60.023
%SiO2	11.65	18.49	39.93	30.03	19.91	10.56	6.92	12.91024
Unit Fe	0.003522	0.001845	0.001189	0.00377	0.003851	0.005035	0.028808	0.048018
Unit SiO2	0.00068	0.000621	0.001246	0.00245	0.001402	0.000862	0.003067	0.010328

Cumulative froth

%wt(overall)	0.12148	0.20232	0.678	2.14656	1.87342	1.75944	8.66878	14.49
Unit Fe	0.054384	0.063678	0.209929	0.960072	1.052456	1.080424	5.712518	9.13346
Unit SiO2	0.036226	0.102666	0.341038	0.734181	0.349682	0.229244	0.589426	2.382463
%Fe	44.76809	31.47374	30.96303	44.72605	56.17834	61.40724	65.8976	63.03285
%SiO2	29.82032	50.74435	50.3006	34.20267	18.66546	13.02939	6.799407	16.44212
Fe recovery	24.34126	6.759095	3.864037	17.40085	18.47949	8.998769	14.78796	13.34385
SiO2 recovery	19.39737	16.86494	31.78145	74.50051	66.42757	45.11173	48.8498	46.75857
Fe loss to size	0.08026	0.093975	0.309813	1.416871	1.553212	1.594486	8.430516	13.47913

Cumulative conc

%wt(overall)	0.4226	1.86091	8.20006	6.59685	6.59571	15.21783	45.65604	85.51
Unit Fe	0.16904	0.878426	5.222973	4.557312	4.64281	10.92592	32.917	59.31348
Unit SiO2	0.15053	0.506088	0.732035	0.25129	0.176729	0.278926	0.617183	2.71278
%Fe	40	47.20411	63.69433	69.08316	70.39136	71.79686	72.0978	69.36438
%SiO2	35.62	27.19573	8.927187	3.809243	2.679456	1.832888	1.351809	3.172471
Fe recovery	75.65874	93.24091	96.13596	82.59915	81.52051	91.00123	85.21204	86.65615
SiO2 recovery	80.60263	83.13506	68.21855	25.49949	33.57243	54.88827	51.1502	53.24143

5 min froth

%wt		4.9	5.4	14.3	10.5	14.1	50.8	100
%wt(overall)		0.00147	0.00162	0.00429	0.00315	0.00423	0.01524	0.03
%Fe		52.4	35	43.2	52.3	60.5	65.5	57.9312
%SiO2		21.79	45.3	33.38	22.47	12.22	6.77	15.80878
Unit Fe		0.00077	0.000567	0.001853	0.001647	0.002559	0.009982	0.017379
Unit SiO2		0.00032	0.000734	0.001432	0.000708	0.000517	0.001032	0.004743

Cumulative froth

%wt(overall)	0.12148	0.20379	0.67962	2.15085	1.87657	1.76367	8.68402	14.52
Unit Fe	0.054384	0.064448	0.210496	0.961925	1.054104	1.082983	5.7225	9.15084
Unit SiO2	0.036226	0.102986	0.341772	0.735613	0.35039	0.229761	0.590457	2.387206
%Fe	44.76809	31.62469	30.97266	44.72301	56.17183	61.40506	65.8969	63.02231
%SiO2	29.82032	50.53549	50.28868	34.20102	18.67185	13.02745	6.799356	16.44081
Fe recovery	24.34126	6.840857	3.874473	17.43444	18.50842	9.020084	14.8138	13.36924
SiO2 recovery	19.39737	16.91755	31.84984	74.64582	66.56203	45.21345	48.9353	46.85165
Fe loss to size	0.08026	0.095112	0.31065	1.419606	1.555643	1.598263	8.445248	13.50478

Final conc.

%wt	0.5	2.2	9.7	7.8	7.8	18	54	100
%wt(overall)	0.4226	1.85944	8.19844	6.59256	6.59256	15.2136	45.6408	85.48
%Fe	40	47.2	63.7	69.1	70.4	71.8	72.1	69.3684
%SiO2	35.62	27.2	8.92	3.79	2.67	1.83	1.35	3.168037
Unit Fe	0.16904	0.877656	5.222406	4.555459	4.641162	10.92336	32.90702	59.2961
Unit SiO2	0.15053	0.505768	0.731301	0.249858	0.176021	0.278409	0.616151	2.708038
Fe recovery	75.65874	93.15914	96.12553	82.56556	81.49158	90.97992	85.1862	86.63076
SiO2 recovery	80.60263	83.08245	68.15016	25.35418	33.43797	54.78655	51.0647	53.14835

Composite								
%wt(overall)	0.54408	2.06323	8.87806	8.74341	8.46913	16.97727	54.32482	100
Unit Fe	0.223424	0.942104	5.432903	5.517384	5.695266	12.00635	38.62952	68.44694
Unit SiO2	0.186756	0.608754	1.073073	0.985471	0.526412	0.50817	1.206608	5.095243
%Fe	41.0646	45.66159	61.19471	63.10334	67.24736	70.72013	71.10841	68.44694
%SiO2	34.32507	29.5049	12.08679	11.27101	6.215651	2.993238	2.221099	5.095243

Magnetic Field Flotation Size Analyses

Flotation test No. 4 (no mag sheet)

Products	100 mesh	150mesh	200 mesh	270 mesh	400 mesh	500 mesh	-500 mesh	sum
0.5 min froth								
%wt		1.4	4.9	14.9	14.1	8.4	56.3	100
%wt(overall)		0.13	0.44	1.34	1.27	0.76	5.07	9.01
%Fe		32.2	33	46.8	59.4	64	66.3	60.11509
%SiO2		48.27	48.09	30.63	15.57	9.15	6.18	14.04433
Unit Fe		0.04186	0.1452	0.62712	0.75438	0.4864	3.36141	5.41637
Unit SiO2		0.062751	0.211596	0.410442	0.197739	0.06954	0.313326	1.265394
Fe recovery		16.34666	16.46548	8.954201	6.8221	3.72582	9.564846	8.035054
SiO2 recovery		21.97054	23.40615	22.55365	21.1868	14.26046	25.006136	22.24272
Fe loss to size		0.062098	0.215398	0.930307	1.119092	0.721555	4.9865154	8.034965
Cumulative conc								
%wt(overall)		0.56218	1.88051	10.57521	15.16159	17.80055	44.98578	90.99
Unit Fe		0.214217	0.736645	6.37652	10.30351	12.56845	31.781968	61.99288
Unit SiO2		0.222863	0.692423	1.409405	0.735573	0.418102	0.9396705	4.423631
%Fe		38.10467	39.17262	60.29686	67.95795	70.60706	70.648921	68.13154
%SiO2		39.64268	36.82101	13.32745	4.851557	2.348816	2.0888166	4.861668
Fe recovery		83.65334	83.53452	91.0458	93.1779	96.27418	90.435154	91.96495
SiO2 recovery		78.02946	76.59385	77.44635	78.8132	85.73954	74.993864	77.75728
1 min froth								
%wt		1.2	3.2	11.4	14.4	13.9	55.9	100
%wt(overall)		0.09192	0.24512	0.87324	1.10304	1.06474	4.28194	7.66
%Fe		32.3	31.2	44.5	58.4	65.5	68.4	62.2087
%SiO2		49.3	51.24	33.59	15.55	7.43	4.7	11.95981
Unit Fe		0.02969	0.076477	0.388592	0.644175	0.697405	2.928847	4.765186
Unit SiO2		0.045317	0.125599	0.293321	0.171523	0.07911	0.2012512	0.916121
Cumulative froth								
%wt(overall)		0.22192	0.68512	2.21324	2.37304	1.82474	9.35194	16.67
Unit Fe		0.07155	0.221677	1.015712	1.398555	1.183805	6.290257	10.18156
Unit SiO2		0.108068	0.337195	0.703763	0.369262	0.14865	0.5145772	2.181515
%Fe		32.24142	32.356	45.89253	58.93518	64.87525	67.26152	61.07712
%SiO2		48.69663	49.217	31.79788	15.5607	8.146376	5.5023576	13.08648
Fe recovery		27.94089	25.13791	14.50263	12.64758	9.067933	17.89884	15.10409
SiO2 recovery		37.8369	37.29961	38.67156	39.56466	30.48346	41.067728	38.34603
Fe loss to size		0.106142	0.328849	1.506767	2.0747	1.756126	9.331341	15.10393
Cumulative conc								
%wt(overall)		0.47026	1.63539	9.70197	14.05855	16.73581	40.70384	83.33
Unit Fe		0.184527	0.660168	5.987928	9.65933	11.87104	28.853121	57.2277
Unit SiO2		0.177547	0.566823	1.116084	0.56405	0.338992	0.7384193	3.50751
%Fe		39.23929	40.3676	61.71868	68.70787	70.93198	70.885502	68.67598
%SiO2		37.755	34.65983	11.50368	4.012152	2.025549	1.8141268	4.20918
Fe recovery		72.05911	74.86209	85.49737	87.35242	90.93207	82.10116	84.89591
SiO2 recovery		62.1631	62.70039	61.32844	60.43534	69.51654	58.932272	61.65397

1.5 min froth

%wt		1.1	2.9	10.8	13.9	14.2	57.1	100
%wt(overall)		0.07095	0.18705	0.6966	0.89655	0.9159	3.68295	6.45
%Fe		28.4	30.9	44.8	60.6	66.4	67.8	62.6129
%SiO2		51.65	50.36	32.21	12.96	7.06	3.74	10.44677
Unit Fe		0.02015	0.057798	0.312077	0.543309	0.608158	2.4970401	4.038532
Unit SiO2		0.036646	0.094198	0.224375	0.116193	0.064663	0.1377423	0.673817

Cumulative froth

%wt(overall)		0.29287	0.87217	2.90984	3.26959	2.74064	13.03489	23.12
Unit Fe		0.0917	0.279476	1.327789	1.941865	1.791962	8.7872971	14.22009
Unit SiO2		0.144713	0.431394	0.928138	0.485455	0.213313	0.6523195	2.855332
%Fe		31.31081	32.04374	45.63098	59.39169	65.38481	67.413665	61.50557
%SiO2		49.41211	49.46213	31.89654	14.84757	7.783318	5.0044113	12.35005
Fe recovery		35.80955	31.69218	18.95855	17.5609	13.72641	25.004133	21.09516
SiO2 recovery		50.66738	47.71956	51.00088	52.01418	43.7437	52.060762	50.19018
Fe loss to size		0.136033	0.414591	1.969721	2.880677	2.658303	13.035599	21.09492

Cumulative conc

%wt(overall)	0.02418	0.39931	1.44834	9.00537	13.162	15.81991	37.02089	76.88
Unit Fe	0.011583	0.164377	0.602369	5.675851	9.116021	11.26288	26.356081	53.18917
Unit SiO2	0.005594	0.140901	0.472625	0.891709	0.447858	0.274329	0.600677	2.833693
%Fe	47.90471	41.16523	41.59032	63.02741	69.26015	71.19436	71.192457	69.18466
%SiO2	23.13623	35.28611	32.63219	9.901971	3.402655	1.734077	1.6225351	3.685865
Fe recovery	100	64.19045	68.30782	81.04145	82.4391	86.27359	74.995867	78.90484
SiO2 recovery	100	49.33262	52.28044	48.99912	47.98582	56.2563	47.939238	49.80982

2.5 min froth

%wt	0.5	0.8	3.3	11.9	14.1	9.8	59.6	100
%wt(overall)	0.02055	0.03288	0.13563	0.48909	0.57951	0.40278	2.44956	4.11
%Fe	46	29.9	31.1	45	62.2	67.4	68.4	62.9923
%SiO2	24.95	51.66	48.41	29.41	11.39	5.49	4.22	10.29448
Unit Fe	0.009453	0.009831	0.042181	0.220091	0.360455	0.271474	1.675499	2.588984
Unit SiO2	0.005127	0.016986	0.065658	0.143841	0.066006	0.022113	0.1033714	0.423103

Cumulative froth

%wt(overall)	0.02055	0.32575	1.0078	3.39893	3.8491	3.14342	15.48445	27.23
Unit Fe	0.009453	0.101531	0.321657	1.547879	2.30232	2.063436	10.462796	16.80907
Unit SiO2	0.005127	0.161699	0.497052	1.07198	0.551461	0.235425	0.7556909	3.278435
%Fe	46	31.16841	31.91673	45.54019	59.8145	65.64303	67.569698	61.72997
%SiO2	24.95	49.639	49.32053	31.53874	14.32701	7.489465	4.8803215	12.03979
Fe recovery	81.60845	39.64868	36.47543	22.10107	20.82062	15.8059	29.771743	24.93585
SiO2 recovery	91.65022	56.61449	54.98252	58.90492	59.08643	48.2783	60.3107	57.62736
Fe loss to size	0.014023	0.150617	0.477165	2.296216	3.415398	3.061024	15.521134	24.93558

Cumulative conc

%wt(overall)	0.00363	0.36643	1.31271	8.51628	12.58249	15.41713	34.57133	72.77
Unit Fe	0.00213	0.154546	0.560188	5.455761	8.755566	10.99141	24.680582	50.60018
Unit SiO2	0.000467	0.123915	0.406967	0.747868	0.381851	0.252217	0.4973055	2.41059
%Fe	58.6876	42.17607	42.67418	64.06272	69.58532	71.29349	71.390317	69.5344
%SiO2	12.86818	33.81687	31.00201	8.781625	3.034783	1.635952	1.4384911	3.312615
Fe recovery	18.39155	60.35132	63.52457	77.89893	79.17938	84.1941	70.228257	75.06415
SiO2 recovery	8.349779	43.38551	45.01748	41.09508	40.91357	51.7217	39.6893	42.37264

3.5 min froth

%wt	1.6	2.5	4.6	15.1	13.1	13.6	49.5	100
%wt(overall)	0.00144	0.00225	0.00414	0.01359	0.01179	0.01224	0.04455	0.09
%Fe	57.3	49.9	36.3	45.4	57.9	65.9	66.8	60.3028
%SiO2	15.39	26.24	41.73	29.7	14.78	6.4	5.51	12.84055
Unit Fe	0.000825	0.001123	0.001503	0.00617	0.006826	0.008066	0.0297594	0.054273
Unit SiO2	0.000222	0.00059	0.001728	0.004036	0.001743	0.000783	0.0024547	0.011556

Cumulative froth

%wt(overall)	0.02199	0.328	1.01194	3.41252	3.86089	3.15566	15.529	27.32
Unit Fe	0.010278	0.102654	0.32316	1.554049	2.309146	2.071502	10.492556	16.86334
Unit SiO2	0.005349	0.162289	0.49878	1.076016	0.553203	0.236209	0.7581456	3.289992
%Fe	46.73997	31.2969	31.93466	45.53963	59.80865	65.64402	67.56749	61.72527
%SiO2	24.32397	49.47849	49.28948	31.53141	14.32839	7.485239	4.8821279	12.04243
Fe recovery	88.73177	40.08712	36.64585	22.18916	20.88235	15.86769	29.856423	25.01636
SiO2 recovery	95.61165	56.82121	55.17362	59.12671	59.27314	48.43895	60.506607	57.8305
Fe loss to size	0.015247	0.152283	0.479394	2.305369	3.425525	3.072989	15.56528	25.01609

Cumulative conc

%wt(overall)	0.00219	0.36418	1.30857	8.50269	12.5707	15.40489	34.52678	72.68
Unit Fe	0.001305	0.153423	0.558685	5.449591	8.748739	10.98334	24.650823	50.54591
Unit SiO2	0.000245	0.123325	0.405239	0.743832	0.380109	0.251433	0.4948508	2.399034
%Fe	59.6	42.12835	42.69435	64.09255	69.59628	71.29777	71.39624	69.54583
%SiO2	11.21	33.86369	30.96807	8.748191	3.023768	1.632166	1.4332377	3.300817
Fe recovery	11.26823	59.91288	63.35415	77.81084	79.11765	84.13231	70.143577	74.98364
SiO2 recovery	4.388346	43.17879	44.82638	40.87329	40.72686	51.56105	39.493393	42.1695

5 min froth

%wt	7.3	3.1	2.9	8.8	7.5	10.3	60.1	100
%wt(overall)	0.00219	0.00093	0.00087	0.00264	0.00225	0.00309	0.01803	0.03
%Fe	59.6	53.2	34.2	40.1	48.8	60.2	64.2	58.9654
%SiO2	11.21	19.68	43.1	35.12	24.07	12.43	7.63	13.44004
Unit Fe	0.001305	0.000495	0.000298	0.001059	0.001098	0.00186	0.0115753	0.01769
Unit SiO2	0.000245	0.000183	0.000375	0.000927	0.000542	0.000384	0.0013757	0.004032

Cumulative froth

%wt(overall)	0.02418	0.32893	1.01281	3.41516	3.86314	3.15875	15.54703	27.35
Unit Fe	0.011583	0.103149	0.323457	1.555108	2.310244	2.073362	10.504131	16.88103
Unit SiO2	0.005594	0.162472	0.499155	1.076943	0.553745	0.236593	0.7595213	3.294024
%Fe	47.90471	31.35883	31.93661	45.53542	59.80224	65.6387	67.563585	61.72225
%SiO2	23.13623	49.39424	49.28416	31.53419	14.33406	7.490076	4.8853147	12.04396
Fe recovery	100	40.28033	36.67959	22.20428	20.89228	15.88194	29.88936	100
SiO2 recovery	100	56.88529	55.2151	59.17765	59.33116	48.51771	60.616399	57.90137
Fe loss to size	0.017183	0.153017	0.479836	2.306939	3.427154	3.075749	15.582452	25.04233

Final conc.

%wt	0.5	1.8	11.7	17.3	21.2	47.5	100
%wt(overall)	0.36325	1.3077	8.50005	12.56845	15.4018	34.50875	72.65
%Fe	42.1	42.7	64.1	69.6	71.3	71.4	69.5502
%SiO2	33.9	30.96	8.74	3.02	1.63	1.43	3.29663
Unit Fe	0.152928	0.558388	5.448532	8.747641	10.98148	24.639248	50.52822
Unit SiO2	0.123142	0.404864	0.742904	0.379567	0.251049	0.4934751	2.395002
Fe recovery	59.71967	63.32041	77.79572	79.10772	84.11806	70.11064	74.95739
SiO2 recovery	43.11471	44.7849	40.82235	40.66884	51.48229	39.383601	42.09863

Composite

%wt(overall)	0.02418	0.69218	2.32051	11.91521	16.43159	18.56055	50.05578	100
Unit Fe	0.011583	0.256077	0.881845	7.00364	11.05789	13.05485	35.143378	67.40925
Unit SiO2	0.005594	0.285614	0.904019	1.819847	0.933312	0.487642	1.2529965	5.689025
%Fe	47.90471	36.9957	38.00221	58.77899	67.2965	70.33652	70.208432	67.40925
%SiO2	23.13623	41.263	38.95777	15.27331	5.679987	2.627304	2.5032004	5.689025

Magnetic Field Flotation Size Analyses

Flotation test No. 5 (mag sheet 4 layers)

Products	100 mesh	150mesh	200 mesh	270 mesh	400 mesh	500 mesh	-500 mesh	sum
0.5 min froth								
%wt	1.6	1.2	3.4	12.2	12.8	14.1	54.7	100
%wt(overall)	0.08112	0.06084	0.17238	0.61854	0.64896	0.71487	2.77329	5.07
%Fe	42	32.4	28.8	39.3	49.2	56.4	63.1	55.6003
%SiO2	32.92	47.72	56.25	36.34	25.74	17.69	10.53	18.99426
Unit Fe	0.03407	0.019712	0.049645	0.243086	0.319288	0.403187	1.749946	2.818935
Unit SiO2	0.026705	0.029033	0.096964	0.224777	0.167042	0.126461	0.292027	0.963009
Fe recovery	21.09	9.22526	4.727319	4.047094	3.155817	3.368194	4.575056	4.166415
SiO2 recovery	71.03868	12.49771	11.80063	15.62967	19.6497	22.87476	21.5292	18.20746
Fe loss to size	0.050356	0.029135	0.073376	0.359284	0.471911	0.595914	2.586438	4.166415
Cumulative conc								
%wt(overall)	0.03686	0.51429	2.29258	9.54539	14.38367	16.47704	51.68017	94.93
Unit Fe	0.016585	0.193964	1.000536	5.763353	9.798164	11.56723	36.49977	64.8396
Unit SiO2	0.010887	0.203272	0.724719	1.213368	0.683059	0.426378	1.064398	4.326081
%Fe	44.99533	37.71487	43.64237	60.37839	68.12006	70.20208	70.62626	68.30254
%SiO2	29.53629	39.52487	31.61151	12.71156	4.748849	2.587711	2.059586	4.557128
Fe recovery	32.7412	90.77474	95.27268	95.95291	96.84418	96.63181	95.42494	95.83359
SiO2 recovery	28.96132	87.50229	88.19937	84.37033	80.3503	77.12524	78.4708	81.79254
1 min froth								
%wt	0.4	1	3.2	12.3	11.3	10.3	61.5	100
%wt(overall)	0.01644	0.0411	0.13152	0.50553	0.46443	0.42333	2.52765	4.11
%Fe	41.2	28.7	28.4	41.5	53.6	60.3	65.4	58.9538
%SiO2	33.44	49.97	54.88	36.3	22.5	14.37	8.13	15.87708
Unit Fe	0.006773	0.011796	0.037352	0.209795	0.248934	0.255268	1.653083	2.423001
Unit SiO2	0.005498	0.020538	0.072178	0.183507	0.104497	0.060833	0.205498	0.652548
Cumulative froth								
%wt(overall)	0.09756	0.10194	0.3039	1.12407	1.11339	1.1382	5.30094	9.18
Unit Fe	0.040844	0.031508	0.086997	0.452881	0.568223	0.658455	3.403029	5.241936
Unit SiO2	0.032202	0.049571	0.169142	0.408285	0.271539	0.187293	0.497525	1.615557
%Fe	41.86519	30.90824	28.62689	40.28941	51.03538	57.85052	64.19671	57.1017
%SiO2	33.00763	48.62715	55.6571	36.32201	24.38849	16.45519	9.385607	17.59866
Fe recovery	80.63001	14.74563	8.284007	7.539928	5.616263	5.500685	8.896874	7.747635
SiO2 recovery	85.66298	21.33852	20.58482	28.38967	31.94197	33.87842	36.67916	30.54508
Fe loss to size	0.060367	0.046569	0.128583	0.669363	0.839839	0.973203	5.029712	7.747635
Cumulative conc								
%wt(overall)	0.02042	0.47319	2.16106	9.03986	13.91924	16.05371	49.15252	90.82
Unit Fe	0.009812	0.182168	0.963185	5.553558	9.54923	11.31196	34.84669	62.4166
Unit SiO2	0.00539	0.182735	0.652541	1.029861	0.578562	0.365546	0.8589	3.673533
%Fe	48.05093	38.49787	44.57	61.43411	68.60454	70.4632	70.89501	68.72561
%SiO2	26.39344	38.61763	30.19541	11.39244	4.156563	2.277016	1.747418	4.044851
Fe recovery	19.36999	85.25437	91.71599	92.46007	94.38374	94.49931	91.10313	92.25236
SiO2 recovery	14.33702	78.66148	79.41518	71.61033	68.05803	66.12158	63.32084	69.45492

1.5 min froth

%wt	0.2	0.6	2.4	10.2	11.7	13.7	61.2	100
%wt(overall)	0.01052	0.03156	0.12624	0.53652	0.61542	0.72062	3.21912	5.26
%Fe	38.5	26.5	31	47.9	61.3	65.8	67.8	63.5461
%SiO2	38	64.43	60.16	27.29	12.35	6.87	4.26	9.68326
Unit Fe	0.00405	0.008363	0.039134	0.256993	0.377252	0.474168	2.182563	3.342525
Unit SiO2	0.003998	0.020334	0.075946	0.146416	0.076004	0.049507	0.137135	0.509339

Cumulative froth

%wt(overall)	0.10808	0.1335	0.43014	1.66059	1.72881	1.85882	8.52006	14.44
Unit Fe	0.044894	0.039871	0.126132	0.709874	0.945475	1.132623	5.585592	8.584461
Unit SiO2	0.0362	0.069905	0.245088	0.554701	0.347543	0.2368	0.63466	2.124896
%Fe	41.53764	29.86611	29.32336	42.74832	54.68937	60.93235	65.55814	59.44918
%SiO2	33.49356	52.36302	56.97864	33.40386	20.10304	12.73924	7.449007	14.71535
Fe recovery	88.62556	18.65969	12.01045	11.81855	9.344993	9.461852	14.60296	12.68792
SiO2 recovery	96.29722	30.0917	29.82756	38.57058	40.8826	42.83341	46.78916	40.17508
Fe loss to size	0.066354	0.05893	0.186424	1.049201	1.397422	1.674028	8.255563	12.68792

Cumulative conc

%wt(overall)	0.0099	0.44163	2.03482	8.50334	13.30382	15.33309	45.9334	85.56
Unit Fe	0.005762	0.173805	0.92405	5.296565	9.171977	10.83779	32.66412	59.07407
Unit SiO2	0.001392	0.162401	0.576595	0.883445	0.502558	0.316039	0.721765	3.164194
%Fe	58.2	39.35527	45.41189	62.28805	68.94243	70.68236	71.11192	69.04403
%SiO2	14.06	36.77302	28.33641	10.38938	3.777544	2.061157	1.57133	3.698216
Fe recovery	11.37444	81.34031	87.98955	88.18145	90.65501	90.53815	85.39704	87.31208
SiO2 recovery	3.702778	69.9083	70.17244	61.42942	59.1174	57.16659	53.21084	59.82492

2.5 min froth

%wt		0.7	2.1	9.2	11.4	13.5	63.1	100
%wt(overall)		0.04529	0.13587	0.59524	0.73758	0.87345	4.08257	6.47
%Fe		32.6	32	50.6	63.1	67.2	68.3	64.9181
%SiO2		44.07	47.38	24.61	10.09	5.43	3.92	7.92442
Unit Fe		0.014765	0.043478	0.301191	0.465413	0.586958	2.788395	4.200201
Unit SiO2		0.019959	0.064375	0.146489	0.074422	0.047428	0.160037	0.51271

Cumulative froth

%wt(overall)	0.10808	0.17879	0.56601	2.25583	2.46639	2.73227	12.60263	20.91
Unit Fe	0.044894	0.054636	0.16961	1.011066	1.410888	1.719581	8.373988	12.78466
Unit SiO2	0.0362	0.089864	0.309463	0.70119	0.421965	0.284228	0.794697	2.637606
%Fe	41.53764	30.55864	29.96589	44.82012	57.20459	62.93598	66.44635	61.14138
%SiO2	33.49356	50.26228	54.6745	31.08345	17.10862	10.40263	6.3058	12.61409
Fe recovery	88.62556	25.56947	16.15053	16.83303	13.94509	14.36526	21.89294	18.89586
SiO2 recovery	96.29722	38.68355	37.66211	48.75651	49.63707	51.41246	58.58758	49.86881
Fe loss to size	0.066354	0.080752	0.250685	1.494365	2.085307	2.541558	12.37684	18.89586

Cumulative conc

%wt(overall)	0.0099	0.39634	1.89895	7.9081	12.56624	14.45964	41.85083	79.09
Unit Fe	0.005762	0.15904	0.880572	4.995373	8.706564	10.25083	29.87573	54.87387
Unit SiO2	0.001392	0.142441	0.51222	0.736956	0.428136	0.268611	0.561729	2.651484
%Fe	58.2	40.1272	46.37151	63.16781	69.28536	70.89271	71.38623	69.38155
%SiO2	14.06	35.93919	26.97384	9.319002	3.407032	1.857658	1.342216	3.35249
Fe recovery	11.37444	74.43053	83.84947	83.16697	86.05491	85.63474	78.10706	81.10414
SiO2 recovery	3.702778	61.31645	62.33789	51.24349	50.36293	48.58754	41.41242	50.13119

3.5 min froth

%wt	9	1.4	2.7	8.8	8.4	7	62.7	100
%wt(overall)	0.0099	0.00154	0.00297	0.00968	0.00924	0.0077	0.06897	0.11
%Fe	58.2	47.1	33.5	42.7	53.5	60	64	59.3815
%SiO2	14.06	28.04	47.17	35.25	22.27	13.39	7.92	13.80737
Unit Fe	0.005762	0.000725	0.000995	0.004133	0.004943	0.00462	0.044141	0.06532
Unit SiO2	0.001392	0.000432	0.001401	0.003412	0.002058	0.001031	0.005462	0.015188

Cumulative froth

%wt(overall)	0.11798	0.18033	0.56898	2.26551	2.47563	2.73997	12.6716	21.02
Unit Fe	0.050656	0.055361	0.170605	1.015199	1.415832	1.724201	8.418129	12.84998
Unit SiO2	0.037592	0.090296	0.310864	0.704602	0.424023	0.285259	0.800159	2.652795
%Fe	42.93582	30.69991	29.98434	44.81106	57.19076	62.92773	66.43304	61.13217
%SiO2	31.86284	50.0725	54.63532	31.10125	17.12788	10.41103	6.314586	12.62034
Fe recovery	100	25.90893	16.24527	16.90185	13.99395	14.40386	22.00834	18.9924
SiO2 recovery	100	38.86943	37.83261	48.99378	49.87913	51.59896	58.99029	50.15597
Fe loss to size	0.07487	0.081824	0.252156	1.500475	2.092614	2.548387	12.44208	18.9924

Cumulative conc

%wt(overall)		0.3948	1.89598	7.89842	12.557	14.45194	41.78186	78.98
Unit Fe		0.158315	0.879577	4.99124	8.701621	10.24621	29.83159	54.80855
Unit SiO2		0.14201	0.510819	0.733544	0.426078	0.26758	0.556266	2.636296
%Fe		40.1	46.39167	63.19289	69.29697	70.89851	71.39842	69.39548
%SiO2		35.97	26.9422	9.287222	3.393152	1.851514	1.331358	3.337928
Fe recovery		74.09107	83.75473	83.09815	86.00605	85.59614	77.99166	81.0076
SiO2 recovery		61.13057	62.16739	51.00622	50.12087	48.40104	41.00971	49.84403

5 min froth

%wt			4.7	12.1	11.8	11.3	60.1	100
%wt(overall)			0.00094	0.00242	0.00236	0.00226	0.01202	0.02
%Fe			29.6	40	53.2	61.4	65.9	59.0529
%SiO2			51.54	32.85	20.16	11.53	6.05	13.71505
Unit Fe			0.000278	0.000968	0.001256	0.001388	0.007921	0.011811
Unit SiO2			0.000484	0.000795	0.000476	0.000261	0.000727	0.002743

Cumulative froth

%wt(overall)	0.11798	0.18033	0.56992	2.26793	2.47799	2.74223	12.68362	21.04
Unit Fe	0.050656	0.055361	0.170883	1.016167	1.417087	1.725589	8.42605	12.86179
Unit SiO2	0.037592	0.090296	0.311349	0.705397	0.424499	0.28552	0.800886	2.655538
%Fe	42.93582	30.69991	29.9837	44.80593	57.18696	62.92647	66.43253	61.13019
%SiO2	31.86284	50.0725	54.63022	31.10311	17.13077	10.41195	6.314335	12.62138
Fe recovery	100	25.90893	16.27177	16.91796	14.00636	14.41545	22.02905	19.00986
SiO2 recovery	100	38.86943	37.89157	49.04906	49.93509	51.64609	59.0439	50.20783
Fe loss to size	0.07487	0.081824	0.252567	1.501905	2.094469	2.550438	12.45379	19.00986

Final conc.

%wt		0.5	2.4	10	15.9	18.3	52.9	100
%wt(overall)		0.3948	1.89504	7.896	12.55464	14.44968	41.76984	78.96
%Fe		40.1	46.4	63.2	69.3	70.9	71.4	69.3981
%SiO2		35.97	26.93	9.28	3.39	1.85	1.33	3.3353
Unit Fe		0.158315	0.879299	4.990272	8.700366	10.24482	29.82367	54.79674
Unit SiO2		0.14201	0.510334	0.732749	0.425602	0.267319	0.555539	2.633553
Fe recovery		74.09107	83.72823	83.08204	85.99364	85.58455	77.97095	80.99014
SiO2 recovery		61.13057	62.10843	50.95094	50.06491	48.35391	40.9561	49.79217

Composite

%wt(overall)	0.11798	0.57513	2.46496	10.16393	15.03263	17.19191	54.45346	100
Unit Fe	0.050656	0.213676	1.050182	6.006439	10.11745	11.97041	38.24972	67.65853
Unit SiO2	0.037592	0.232305	0.821683	1.438146	0.850101	0.552839	1.356425	5.28909
%Fe	42.93582	37.15263	42.60441	59.09564	67.30328	69.62817	70.24295	67.65853
%SiO2	31.86284	40.39179	33.33453	14.1495	5.655039	3.215691	2.490981	5.28909

Magnetic Field Flotation Size Analyses

Flotation test No. 6 (mag sheet 2 layers)

Products	100 mesh	150mesh	200 mesh	270 mesh	400 mesh	500 mesh	-500 mesh	sum
0.5 min froth								
%wt		0.8	3.4	13.8	13.2	12.4	56.4	100
%wt(overall)		0.06128	0.26044	1.05708	1.01112	0.94984	4.32024	7.66
%Fe		27.2	29.3	43	54.4	60.3	64.4	58.1274
%SiO2		56.48	53.46	35.2	21.84	14.18	9	16.84428
Unit Fe		0.016668	0.076309	0.454544	0.550049	0.572754	2.782235	4.452559
Unit SiO2		0.034611	0.139231	0.372092	0.220829	0.134687	0.388822	1.290272
Fe recovery		7.363644	6.748114	6.940452	5.009351	4.600259	7.667135	6.584182
SiO2 recovery		19.39826	16.16016	22.63534	25.52108	25.58959	28.61936	23.74416
Fe loss to size		0.024648	0.112841	0.672153	0.81338	0.846954	4.114205	6.584182
Cumulative conc								
%wt(overall)		0.4697	2.37973	10.02013	15.24106	16.82725	47.40213	92.34
Unit Fe		0.209689	1.054509	6.09466	10.4304	11.87771	33.50556	63.17253
Unit SiO2		0.143812	0.722339	1.271763	0.644451	0.391649	0.969775	4.143789
%Fe		44.64325	44.31215	60.82416	68.43619	70.58615	70.68366	68.41296
%SiO2		30.61784	30.35384	12.69208	4.228384	2.327469	2.045847	4.487534
Fe recovery		92.63636	93.25189	93.05955	94.99065	95.39974	92.33286	93.41582
SiO2 recovery		80.60174	83.83984	77.36466	74.47892	74.41041	71.38064	76.25584
1 min froth								
%wt		0.6	3.3	13.1	13.2	15	54.8	100
%wt(overall)		0.03534	0.19437	0.77159	0.77748	0.8835	3.22772	5.89
%Fe		28.7	30.4	45.4	58	64.4	67.7	61.5384
%SiO2		53.88	52.26	33.28	17.17	9.66	5.64	13.2137
Unit Fe		0.010143	0.059088	0.350302	0.450938	0.568974	2.185166	3.624612
Unit SiO2		0.019041	0.101578	0.256785	0.133493	0.085346	0.182043	0.778287
Cumulative froth								
%wt(overall)		0.09662	0.45481	1.82867	1.7886	1.83334	7.54796	13.55
Unit Fe		0.026811	0.135397	0.804846	1.000988	1.141728	4.967401	8.077171
Unit SiO2		0.053652	0.240809	0.628877	0.354322	0.220033	0.570865	2.068559
%Fe		27.74864	29.7701	44.01266	55.96487	62.27582	65.81117	59.61012
%SiO2		55.52902	52.94716	34.38987	19.81001	12.00178	7.563169	15.26612
Fe recovery		11.84442	11.9734	12.28922	9.116089	9.170162	13.6889	11.94404
SiO2 recovery		30.0702	27.95	38.25625	40.94886	41.80471	42.01873	38.06654
Fe loss to size		0.039646	0.200218	1.190159	1.480202	1.688319	7.3455	11.94404
Cumulative conc								
%wt(overall)		0.43436	2.18536	9.24854	14.46358	15.94375	44.17441	86.45
Unit Fe		0.199547	0.995421	5.744358	9.979463	11.30873	31.3204	59.54792
Unit SiO2		0.124771	0.620762	1.014978	0.510957	0.306303	0.787732	3.365502
%Fe		45.94041	45.54952	62.11097	68.99718	70.92895	70.90167	68.88134
%SiO2		28.72521	28.40546	10.97447	3.532716	1.921148	1.783231	3.893004
Fe recovery		88.15558	88.0266	87.71078	90.88391	90.82984	86.3111	88.05596
SiO2 recovery		69.9298	72.05	61.74375	59.05114	58.19529	57.98127	61.93346

1.5 min froth							
%wt	0.5	2.9	12.8	13.1	11.1	59.6	100
%wt(overall)	0.0286	0.16588	0.73216	0.74932	0.63492	3.40912	5.72
%Fe	29.3	32.9	51.4	62.2	66.1	68.8	64.1699
%SiO2	51.6	46.31	23.04	10.78	6.83	3.88	9.0329
Unit Fe	0.00838	0.054575	0.37633	0.466077	0.419682	2.345475	3.670518
Unit SiO2	0.014758	0.076819	0.16869	0.080777	0.043365	0.132274	0.516682
Cumulative froth							
%wt(overall)	0.12522	0.62069	2.56083	2.53792	2.46826	10.95708	19.27
Unit Fe	0.035191	0.189972	1.181177	1.467065	1.56141	7.312876	11.74769
Unit SiO2	0.06841	0.317628	0.797567	0.435099	0.263398	0.703139	2.585241
%Fe	28.10297	30.60657	46.12475	57.80579	63.25953	66.7411	60.96362
%SiO2	54.63164	51.17337	31.14486	17.14391	10.67142	6.41721	13.41588
Fe recovery	15.54644	16.79951	18.03542	13.3607	12.54098	20.15244	17.37179
SiO2 recovery	38.34133	36.86616	48.51808	50.28419	50.04374	51.75479	47.57475
Fe loss to size	0.052038	0.280919	1.746654	2.169409	2.308921	10.81385	17.37179
Cumulative conc							
%wt(overall)	0.40576	2.01948	8.51638	13.71426	15.30883	40.76529	80.73
Unit Fe	0.191167	0.940846	5.368028	9.513386	10.88905	28.97492	55.8774
Unit SiO2	0.110013	0.543943	0.846288	0.430181	0.262938	0.655458	2.84882
%Fe	47.11331	46.58855	63.0318	69.36857	71.12923	71.07743	69.21516
%SiO2	27.11288	26.93478	9.937182	3.136739	1.717558	1.607882	3.528825
Fe recovery	84.45356	83.20049	81.96458	86.6393	87.45902	79.84756	82.62821
SiO2 recovery	61.65867	63.13384	51.48192	49.71581	49.95626	48.24521	52.42525
2.5 min froth							
%wt	0.5	2.5	11.2	12	11.2	62.6	100
%wt(overall)	0.0298	0.149	0.66752	0.7152	0.66752	3.73096	5.96
%Fe	30.6	34.1	51.9	63.5	67.5	69	65.1923
%SiO2	48.14	48.66	20.2	9.44	5.27	3.66	7.7338
Unit Fe	0.009119	0.050809	0.346443	0.454152	0.450576	2.574362	3.885461
Unit SiO2	0.014346	0.072503	0.134839	0.067515	0.035178	0.136553	0.460934
Cumulative froth							
%wt(overall)	0.15502	0.76969	3.22835	3.25312	3.13578	14.68804	25.23
Unit Fe	0.044309	0.240781	1.527619	1.921217	2.011986	9.887238	15.63315
Unit SiO2	0.082755	0.390131	0.932406	0.502614	0.298577	0.839692	3.046175
%Fe	28.58298	31.28284	47.31889	59.05767	64.16221	67.31489	61.96254
%SiO2	53.38373	50.68682	28.88181	15.4502	9.52161	5.716842	12.07362
Fe recovery	19.57494	21.29262	23.32527	17.4967	16.15993	27.24673	23.11738
SiO2 recovery	46.38162	45.28142	56.72069	58.08686	56.72736	61.80584	56.05707
Fe loss to size	0.065522	0.356053	2.258954	2.840982	2.975206	14.62067	23.11738
Cumulative conc							
%wt(overall)	0.37596	1.87048	7.84886	12.99906	14.64131	37.03433	74.77
Unit Fe	0.182048	0.890037	5.021585	9.059234	10.43848	26.40056	51.99194
Unit SiO2	0.095667	0.471439	0.711449	0.362666	0.22776	0.518905	2.387886
%Fe	48.42222	47.58337	63.97852	69.69145	71.29469	71.28672	69.53583
%SiO2	25.44619	25.20418	9.064362	2.789938	1.555596	1.401145	3.193641
Fe recovery	80.42506	78.70738	76.67473	82.5033	83.84007	72.75327	76.88262
SiO2 recovery	53.61838	54.71858	43.27931	41.91314	43.27264	38.19416	43.94293

3.5 min froth							
%wt	2.9	2.9	7.8	5.8	5.5	75.1	100
%wt(overall)	0.00261	0.00261	0.00702	0.00522	0.00495	0.06759	0.09
%Fe	51.6	36.5	42.6	50.2	56.7	64.4	60.2722
%SiO2	22.04	41.36	33.94	25.42	17.05	7.19	12.29772
Unit Fe	0.001347	0.000953	0.002991	0.00262	0.002807	0.043528	0.054245
Unit SiO2	0.000575	0.001079	0.002383	0.001327	0.000844	0.00486	0.011068
Cumulative froth							
%wt(overall)	0.15763	0.7723	3.23537	3.25834	3.14073	14.75563	25.32
Unit Fe	0.045656	0.241734	1.53061	1.923837	2.014792	9.930766	15.68739
Unit SiO2	0.083331	0.391211	0.934789	0.50394	0.299421	0.844552	3.057243
%Fe	28.96409	31.30048	47.30865	59.04347	64.15045	67.30154	61.95654
%SiO2	52.86475	50.6553	28.89279	15.46617	9.533476	5.72359	12.07442
Fe recovery	20.16991	21.37687	23.37093	17.52057	16.18247	27.36668	23.1976
SiO2 recovery	46.70403	45.40672	56.86563	58.24021	56.88771	62.16354	56.26074
Fe loss to size	0.067514	0.357461	2.263376	2.844857	2.979356	14.68503	23.1976
Cumulative conc							
%wt(overall)	0.37335	1.86787	7.84184	12.99384	14.63636	36.96674	74.68
Unit Fe	0.180701	0.889085	5.018594	9.056613	10.43567	26.35703	51.93769
Unit SiO2	0.095092	0.47036	0.709067	0.361339	0.226916	0.514045	2.376818
%Fe	48.4	47.59886	63.99766	69.69928	71.29962	71.29931	69.54699
%SiO2	25.47	25.18161	9.042094	2.780847	1.550356	1.39056	3.18267
Fe recovery	79.83009	78.62313	76.62907	82.47943	83.81753	72.63332	76.8024
SiO2 recovery	53.29597	54.59328	43.13437	41.75979	43.11229	37.83646	43.73926
5 min froth							
%wt		11.2	14.9	12.6	10.4	50.9	100
%wt(overall)		0.00112	0.00149	0.00126	0.00104	0.00509	0.01
%Fe		45.7	51.7	62.3	66	66.3	61.2822
%SiO2		27.86	20.06	11.51	6.56	5.46	11.0209
Unit Fe		0.000512	0.00077	0.000785	0.000686	0.003375	0.006128
Unit SiO2		0.000312	0.000299	0.000145	6.82E-05	0.000278	0.001102
Cumulative froth							
%wt(overall)	0.15763	0.77342	3.23686	3.2596	3.14177	14.76072	25.33
Unit Fe	0.045656	0.242245	1.53138	1.924622	2.015479	9.934141	15.69352
Unit SiO2	0.083331	0.391523	0.935087	0.504085	0.299489	0.84483	3.058345
%Fe	28.96409	31.32133	47.31067	59.04473	64.15106	67.30119	61.95627
%SiO2	52.86475	50.62229	28.88872	15.46464	9.532491	5.723499	12.074
Fe recovery	20.16991	21.42213	23.38269	17.52772	16.18798	27.37598	23.20666
SiO2 recovery	46.70403	45.44293	56.88381	58.25697	56.90067	62.184	56.28103
Fe loss to size	0.067514	0.358218	2.264515	2.846018	2.980371	14.69002	23.20666
Final conc.							
%wt	0.5	2.5	10.5	17.4	19.6	49.5	100
%wt(overall)	0.37335	1.86675	7.84035	12.99258	14.63532	36.96165	74.67
%Fe	48.4	47.6	64	69.7	71.3	71.3	69.5481
%SiO2	25.47	25.18	9.04	2.78	1.55	1.39	3.18162
Unit Fe	0.180701	0.888573	5.017824	9.055828	10.43498	26.35366	51.93157
Unit SiO2	0.095092	0.470048	0.708768	0.361194	0.226847	0.513767	2.375716
Fe recovery	79.83009	78.57787	76.61731	82.47228	83.81202	72.62402	76.79334
SiO2 recovery	53.29597	54.55707	43.11619	41.74303	43.09933	37.816	43.71897

Composite

%wt(overall)	0.53098	2.64017	11.07721	16.25218	17.77709	51.72237	100
Unit Fe	0.226358	1.130818	6.549204	10.98045	12.45046	36.2878	67.62509
Unit SiO2	0.178423	0.861571	1.643855	0.865279	0.526336	1.358597	5.434061
%Fe	42.63014	42.83127	59.12323	67.56294	70.03656	70.15881	67.62509
%SiO2	33.60257	32.63315	14.83997	5.324081	2.960757	2.62671	5.434061

Exhibit D

Magnetic field application in cationic silica flotation of magnetic taconite concentrates

S. Ersayin and I. Iwasaki
Program director and endowed taconite chair, respectively, Coleraine Minerals Research Laboratory, Natural Resources Research Institute, University of Minnesota Duluth, Coleraine, Minnesota

Abstract
The application of a magnetic field was shown to be effective in controlling iron losses in a pilot-scale cationic silica flotation in the processing of magnetic taconite concentrates. The design of a magnetic-field distribution device and batch-flotation test results using a 1.42-m^3 (50 cu ft) WEMCO flotation cell are reported. Major losses of iron units in froth products were in the -25-µm (-500-mesh) fraction, and the application of a magnetic field decreased the flotation of fine magnetite, thereby improving the selectivity of separation. The "as-received" sample was sufficiently magnetized, and no further benefit was gained by the magnetizing treatment. The selectivity was somewhat adversely affected by demagnetizing the sample, though its effect was minimal due to the magnetic field. The device is simple in construction, low cost and may be readily installed in existing equipment.

Key words: Iron ore, Flotation, Taconite concentrates, Cationic silica flotation, Magnetic field, Flexible magnetic sheet, Magnetizing, Demagnetizing

Introduction

In the cationic silica flotation of magnetic taconite concentrates, iron losses are high due to the simultaneous flotation of fine, well-liberated, high-grade magnetite along with coarse middlings locked with magnetite. Much interest has been expressed by the iron ore industry to develop a means of minimizing the flotation of fine, high-grade magnetite.

Intensive efforts have been made over the years in an attempt to develop more-selective collectors and depressants to remove silica from magnetic taconite concentrates. However, the results have not been encouraging. Some reagents may become an environmental concern in tailing ponds. A magnetic field may be used to depress magnetic minerals, and its use is not only attractive because of its low cost but also because it has no environmental impact.

The use of a magnetic field in flotation was first reported in the processing of a copper sulfide ore for reducing the recovery of magnetic minerals (pyrrhotite and magnetite). In this application, an electromagnet coil around a laboratory column-flotation cell was used (Sonolikar et al., 1988). It was shown that the magnetic minerals were arrested in the magnetization zone, though only low aeration rates were found to achieve low magnetic contents in the froths. Higher air flow rates disturbed the captured magnetic particles, thus allowing them to float into the froths. In laboratory-scale tests, the use of electromagnets is convenient in varying the field strengths at will. However, for commercial-scale equipment, the use of electromagnets would be impractical because of size, design and safety.

Seetharama et al. (1991) carried out a series of tests on magnetic taconite concentrates, applying magnetic fields to laboratory Denver and WEMCO flotation cells. Several configurations of permanent magnets, both static and dynamic, were investigated with promising results. By using a laboratory flotation cell converted into a continuous flotation unit, they showed that fine magnetite particles were effectively depressed and the selectivity of separation was markedly improved.

Wu et al. (1995) tested the use of an electromagnet coil on a 203-mm- (8-in.-) diam flotation column. Encouraged by preliminary test results, they extended the tests using permanent magnets around the flotation column and then in a 1.42-m^3 (50-cu ft) WEMCO flotation cell. In these tests, 12.7-mm- (0.5-in.-) thick magnetic sheets were placed parallel facing each other vertically, and an aluminum frame held the sheets in place. It was found that iron recoveries increased with field intensities up to 0.01 T (100 gauss). They also found that further increases did not improve the iron recovery significantly, that permanent magnetic sheets were shown to be used as effectively as an electromagnet, that the magnetic field needs to be applied to the pulp/froth interface and that the magnetic sheets should cover the entire flotation surface. However, plant trials of placing magnetic sheets in mechanical flotation cells experienced some operational difficulties and tests were discontinued.

In a separate article (Ersayin and Iwasaki, 2002), a magnetic-field distribution device indicated marked advantages in increasing the water rates in a laboratory as well as in a pilot

Preprint number 02-176, presented at the SME Annual Meeting, Feb. 25-27, 2002, Phoenix, Arizona. Revised manuscript received and accepted for publication May 2002. Discussion of this peer-reviewed and approved paper is invited and must be submitted to SME Publications Dept. prior to Feb. 28, 2003.

plant hydroseparator, thereby allowing more efficient desliming. The same device was shown to be effective in preventing the losses of fine, high-grade magnetite particles to the froth in cationic silica flotation using a Denver laboratory flotation cell. The device is simple in construction, low cost and may be installed readily in existing equipment, in both hydroseparators and flotation cells.

Certain layered clay-type silicate minerals commonly present in magnetic taconite, such as minnesotaite, stilpnomelane and greenalite, adsorb excessive amounts of amine collectors by cationic exchange reaction, which may be responsible for the adverse effect on flotation results. In addition, the presence of the layered clay-type minerals in slime fractions with adsorbed collectors appears to be responsible for forming persistent flotation froths. Thorough desliming ahead of flotation in a hydroseparator using this device will cut down the amount of slimes in flotation and, hence, the reagent dosage, thereby alleviating the overly stable froth problem observed in certain plants. Furthermore, the use of the device in flotation cells will not only help prevent excessive losses of iron units in the form of fine, high-grade magnetite, but it is also expected to improve balling by keeping more fines in the final concentrates.

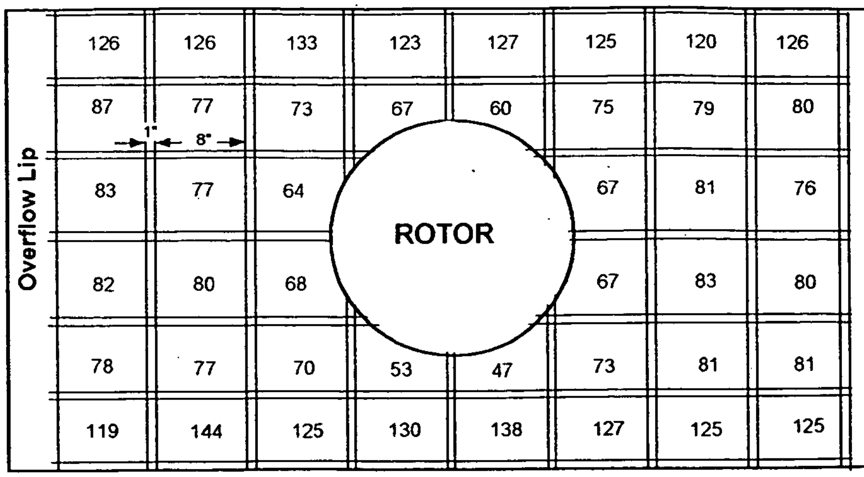

Figure 1 — Gridwork frame of 25.4-mm (1-in.) wide magnetic sheets with 203-mm (8-in.) openings fabricated to fit inside a 1.42-m³ (50-cu ft) WEMCO flotation cell. The numbers in the openings indicate typical values of field strengths in T x 10^4 (gauss) of a gridwork with six layers of magnetic sheets.

It is well known that magnetizing and demagnetizing of magnetic concentrates have profound effects on their flotation behaviors. Magnetizing treatment induces magnetic flocculation and may further improve recovery of the -25-µm (500-mesh) fraction, particularly in the presence of a magnetic field. Alternatively, demagnetizing treatment may release occluded middling particles, thereby improving the selectivity.

In this article, characteristic features of the magnetic-field distribution device are described, and the results of flotation tests using a 1.42-m^3 (50-cu ft) WEMCO flotation cell in a batch mode for investigating the effects of magnetic field strengths and of magnetizing/demagnetizing treatments are reported.

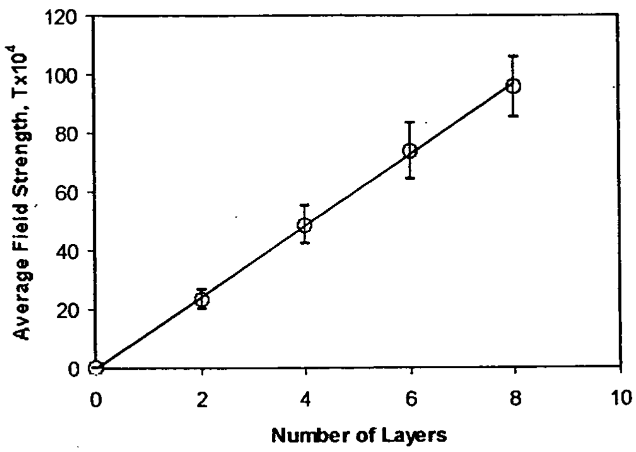

Figure 2 — Average field strengths in T x 10^4 (gauss) of 28 center-row 203-mm (8-in.) openings inside a flotation cell as a function of the number of layers of magnetic sheets.

Flotation test setup

A standard 1.42-m^3 (50-cu ft) WEMCO flotation cell was modified for use as a batch flotation cell. The test procedure was chosen to follow that developed by Wu et al. (1995), except for the magnetic gridwork in applying the magnetic field. In a preliminary series of tests on the design of a magnetic field distribution device, magnetic grids were fabricated from steel sheets by cutting out square frames, either 6.35- or 12.7-mm (0.25- or 0.5-in.) wide, with four, five or six openings, in inside dimensions. High-force flexible magnetic sheets, 6.35-mm (0.25-in.) thick and marketed by Magnet Sales and Manufacturing Co., Culver City, California, were cut into 6.35- or 12.7-mm (0.25- or 0.5-in.) wide strips and placed over the steel frame to construct magnetic gridworks. The field strengths at the centers were at minimum, and the strengths were higher with the wider magnetic sheets and increased with the number of layers.

To investigate if the field strengths might be affected in a multiopening gridwork, nine-opening square frames of 12.7-mm (0.5-in.) strips with 203-, 254-, 305- and 457-mm (8-, 10-, 12- and 18-in.) openings were constructed, and field strengths at the centers of the middle, side and edge squares were measured as a function of the number of layers. It was noted that the field strengths of the middle squares in nine-square frame gridworks gave essentially the same readings with multiopening gridworks beyond nine squares. In the present investigation using a 1.42-m^3 (50-cu ft) WEMCO flotation cell with an inside dimension of 1.27 x 1.71 m (50 by 67.5 in.), a gridwork having 203 mm (8-in.) openings with 25.4-mm- (1-in.-) wide magnetic sheet strips would give a sufficient number of openings with sufficient field strengths. Angle iron, 3.2 mm (0.125-in.-) thick and 25.4-mm- (1-in.-) wide, was welded to form the gridwork, and magnetic strips were placed over the angle iron. No adhesive was used, as the magnetic force was sufficiently strong to hold the angle iron and magnetic strips together.

Figure 1 shows an example of field strength readings of each opening with six layers of magnetic sheets. The side openings had much higher readings than did those in the center rows, but the center four rows were about the same. As magnetite particles will be less likely to go through the side openings, the field strength readings of 28 openings of 203-mm (8-in.) in the center row were averaged and plotted as a function of the number of layers of magnetic sheets in Fig. 2.

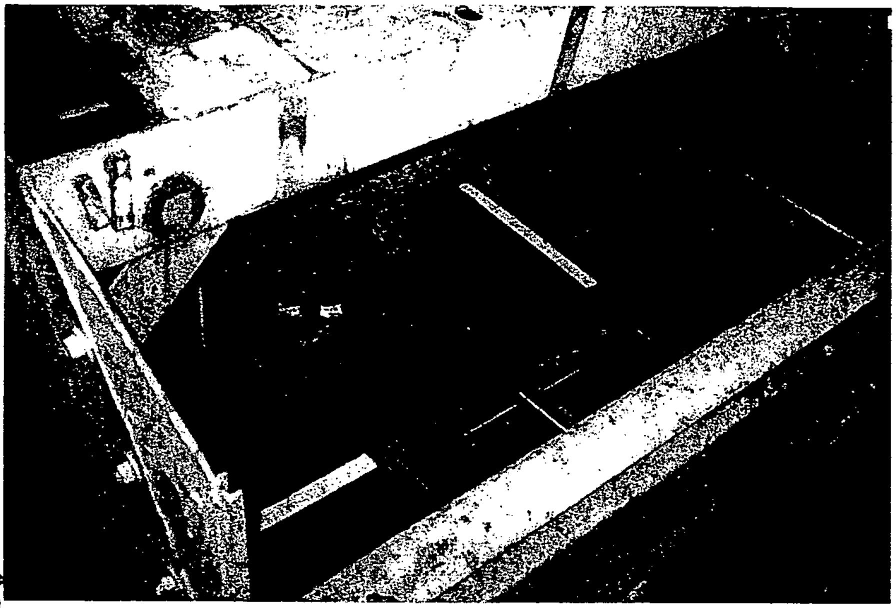

Figure 3 — Gridwork inside flotation cell.

Table 1— Head and screen analysis data of plant flotation feed samples.

Head analysis:

	Fe, %	SiO_2, %
Sample A	67.8	5.47
Sample B	67.3	5.68

Screen analysis:

Size	Sample A			Sample B		
mesh	Wt, %	Fe, %	SiO_2, %	Wt, %	Fe, %	SiO_2, %
150	0.6	36.3	40.94	0.5	39.0	37.79
200	2.2	39.7	35.73	2.6	42.6	32.76
270	11.1	58.4	14.71	10.1	58.9	14.75
400	14.9	66.6	6.01	14.8	66.4	6.51
500	24.7	70.2	3.06	16.4	69.4	3.37
-500	46.5	69.8	2.76	55.6	70.0	2.67
Composite	100.0	67.3	5.60	100.0	67.4	5.53

Though the standard deviations are relatively large, the average values are linearly dependent on the number of layers.

The magnetic gridwork was installed at 152-mm (6-in.) below the overflow lip, so the froth/pulp interface would be located at the half-way point of the six layers of 6.4-mm (0.25-in.) thick magnetic sheets with 127-mm (5-in.) of froth height, as mentioned by Wu et al. (1995).

Figure 3 shows the gridwork with eight layers of magnetic sheet strips. The pulp level was manually controlled by an addition of tap water while observing a rod attached to an air bulb floating at the froth/pulp interface and the rod showing the 127-mm (5-in.) level mark.

Flotation test procedure

A plant flotation feed sample was received in two groups of ten and six 200-L (55-gal) drums with a net weight of approximately 2,300 kg (5,000 lb) and 1,400 kg (3,000 lb) from an operating taconite plant in Minnesota. The head and screen analyses data for the two sets of samples are given in Table 1. It is apparent in the table that the silica contents of +53-μm (-270-mesh) fractions were markedly high, whereas those of -37-μm (-400-mesh) fractions were notably low.

For flotation tests, three drums of the sample were pulped in a 1,500-L (400-gal) sump at 40% solids. Then, to the flotation cell, 300 L (80 gal) of tap water was added, the rotor was turned on and the 40% solid pulp was added to the level of 830 L (220 gal). This volume of pulp was noted to give 127-mm (5-in.) of froth height. The pulp density in the flotation cell became about 25% solids. The first test was performed without magnetic sheets. Subsequent tests were performed successively with eight, six, four and two layers of magnetic sheets.

With magnetic sheet strips on the gridwork, a large amount of magnetite coated the gridwork. A typical example of gridwork with six layers of magnetic strips after a test is shown in Fig. 4. The amount of magnetite attached to the magnetic grid, modified somewhat from that shown in Fig. 2 for convenience of installation, and the effect of the attached magnetite on magnetic field strengths were determined. With six layers of magnetic sheets, the magnetic field strengths at the center of each square averaged 0.0064 ± 0.0011 T (64 ± 11 gauss) in the absence of attached magnetite, whereas with magnetite attached, the field strengths decreased to 0.0034 ± 0.0004 T (33 ± 4 gauss), or a reduction of 47 ± 14%.

Then, the magnetite attached to the magnetic grid was washed off with a strong water jet, dried and weighed. The magnetite thereby removed amounted to 60 kg (132 lb), or approximately 22% of the solids in the cell of about 275 kg (606 lb). The sample analyzed 68.0% Fe and 4.79% SiO_2. Its size distribution was essentially identical to the final concentrates. In an attempt to compensate for this loss of samples, a final concentrate remaining in the cell was used to coat the gridwork, then the final concentrate still in suspension was completely flushed out, and a new sample was introduced into the cell for a subsequent test. In this manner, the loss of magnetite in the new feed in subsequent tests was minimized, as well as the loss of collector by adsorption on magnetite attached to the magnetic grid.

Collector and frother levels were fixed at 54 g/t (0.12 lb/lt) Arosurf MG-82, an ether diamine marketed by Witco Corporation, Dublin, Ohio, and at 9 g/t (0.02 lb/lt) MIBC, which were added as 1% and 0.07% water emulsions, respectively, into the pulp while the rotor was stopped momentarily. Then the rotor was started, the pulp was conditioned for 60 sec and air was turned on. The froth product overflowed into the froth launder was collected in 200-L (55-gal) drums at time intervals of 0.5, 1.0, 1.5, 2.5, 3.5 and 5.0 min. The pulp level was maintained constant during the test by the addition of tap

water. Froth products were filtered, dried, weighed and analyzed for iron and silica. The final concentrate sample remaining in the cell was also sampled, and the solids were analyzed for iron and silica. These flotation tests were performed on an "as-received" sample (Sample A).

A separate sample (Sample B) was used to study the effects of magnetizing and demagnetizing using an identical procedure under the optimal conditions (magnetic gridwork with six layers of magnetic sheets). Initially, a flotation test was performed on the "as-received" sample to establish the baseline flotation data. Then, flotation tests were performed on feed samples, either magnetized or demagnetized. A magnetizing coil, 300-mm- (12-in.-) outer diameter and 180-mm- (7-in.-) inside diameter and with a height of 180 mm (7 in.), was used as a demagnetizing coil by applying 220-v AC, or as a magnetizing coil by applying 50 amp DC from a rectifier, which generated a field strength of 0.035 T (350 gauss).

Figure 4 — Gridwork coated with magnetite after test.

Results and discussion

Cumulative froth weights recovered in a series of tests with eight, six, four, two and no layers of magnetic sheets are plotted against flotation time in Fig. 5. It is evident that in all cases the flotation was essentially complete in about 3 min. Final concentrates after 5 min of flotation all analyzed 3.5% SiO_2 or less, yet the froth weight recoveries are seen to decrease with an increasing number of magnetic sheets, clearly indicating the effectiveness of a magnetic field in preventing magnetite particles from floating into the froths.

In an attempt to determine if this depressant action was selective, the test results were plotted in the form of grade-recovery curves in Fig. 6. It is apparent that the selectivity of separation increased with an increasing number of magnetic sheets to six layers. The results of six and eight layers indicate that an increase in the number of layers beyond six may not improve the selectivity any further. As the composited head grades differed for different numbers of layers, direct comparison of the grade-recovery curves was difficult. In an attempt to bring out the selectivity of separation more clearly, differences in the analytical values of SiO_2 at different time samples and respective composited heads were obtained, and the term "delta SiO_2" is used in this article. These "delta SiO_2" values are plotted against iron recoveries in Fig. 7. The figure suggests that the selectivity improved by increasing the number of layers, even to eight layers.

Size analyses of the froth products and final concentrates of the five tests were made, and the distributions of iron and silica units in different size fractions were calculated. The composited head analyses of iron and silica from all the size fractions were both within a few tenths of a percent, indicating

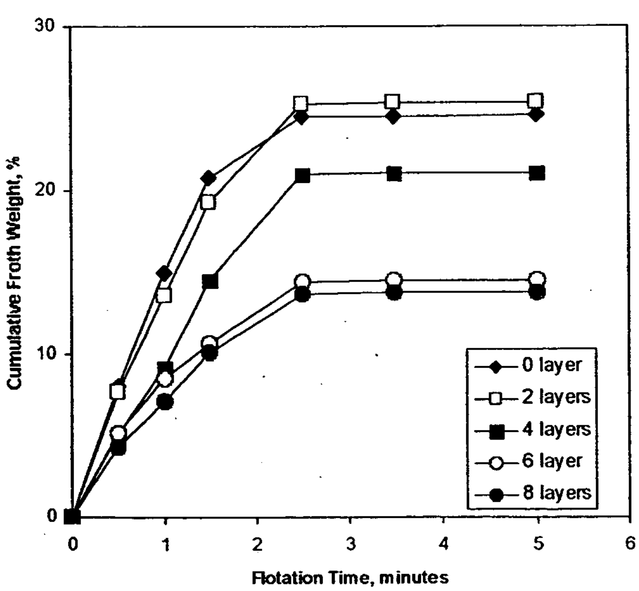

Figure 5 — Cumulative froth weights recovered as a function of flotation time showing the effects of a magnetic field.

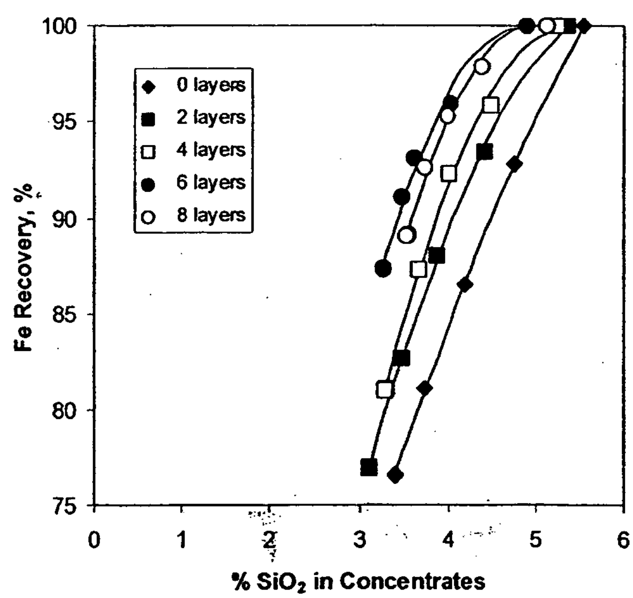

Figure 6 — Grade-recovery plots showing the effect of a magnetic field on flotation results.

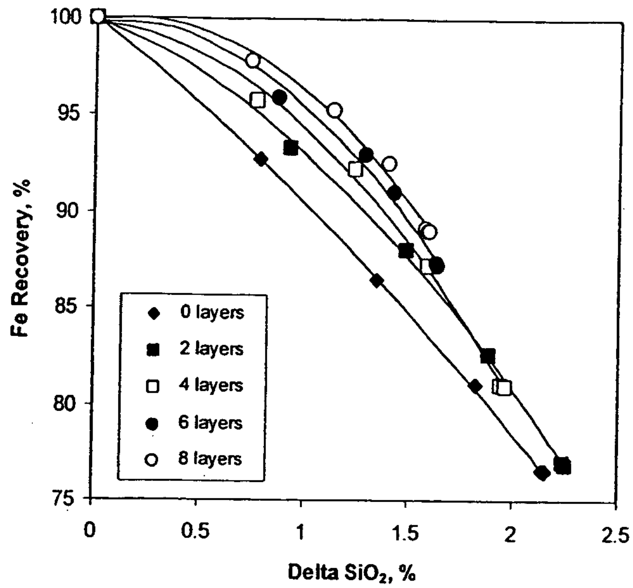

Figure 7 — Grade-recovery plots in terms of "delta SiO_2" showing the effects of a magnetic field.

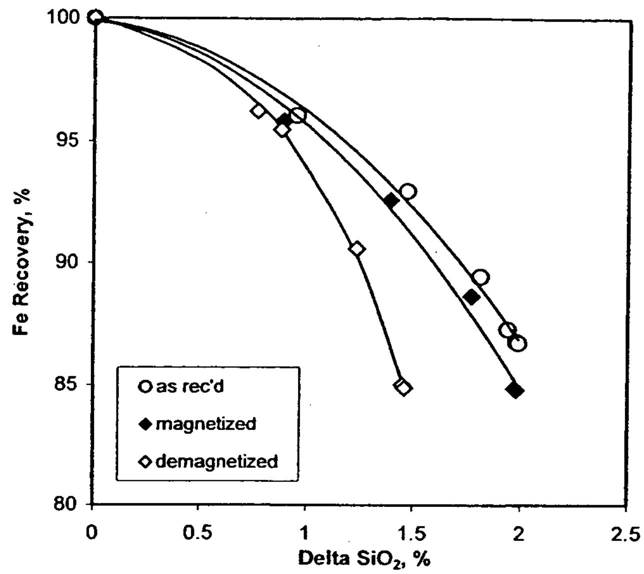

Figure 9 — Grade-recovery plots in terms of "delta SiO_2" showing the effects of magnetizing and demagnetizing on flotation results (magnetic gridwork with six layers of magnetic sheets).

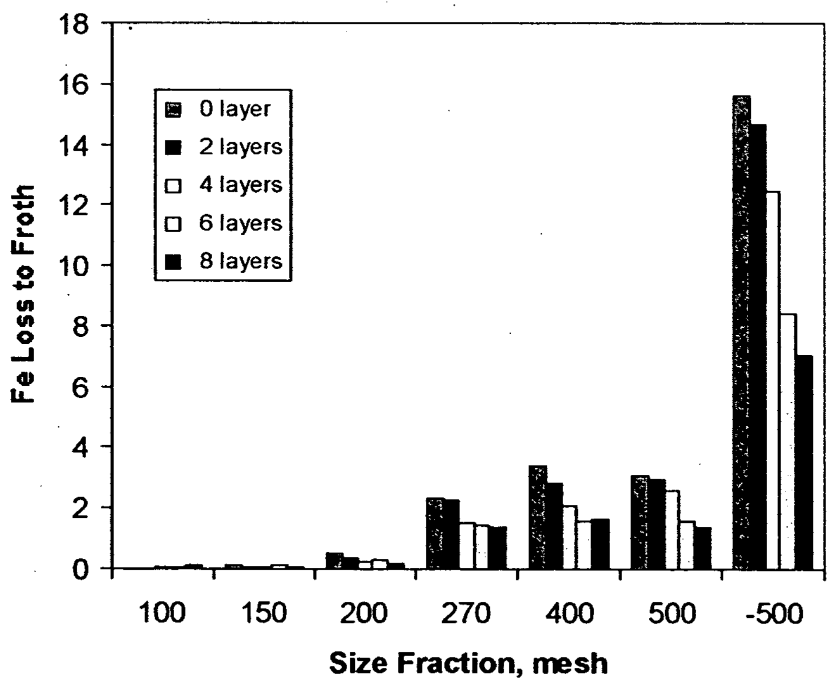

Figure 8 — Iron losses to different size fractions of total froths expressed as percentages of total iron units in feed sample.

that the material balances of the results were satisfactory. To indicate the size fraction(s) where major iron losses occurred, iron losses for different size fractions of total froths expressed as percentages of the total iron units in the feed sample are plotted as a bar graph in Fig. 8. It is apparent that the major losses occurred in the -25-µm (500-mesh) fraction and the magnetic field had a profound influence in depressing this size fraction.

The effects of magnetizing and demagnetizing on flotation results with six layers of magnetic sheets were determined on Sample B, and results were compared with its "as received" sample in the form of grade-recovery curves. The curves with the "as-received" and magnetized samples were quite similar. With the demagnetized sample, the SiO_2 analysis of the composited head was appreciably lower than the other two samples, and the grade-recovery curves could not be compared directly. Hence, the test results were converted to "delta SiO_2" and plotted against iron recoveries in Fig. 9. The selectivity of separation is adversely affected by demagnetizing the feed sample. A bar graph showing the iron losses to different size fractions indicated that the major losses of iron units occurred in the -25-µm (500-mesh) fraction, but differences in the losses after magnetizing and demagnetizing treatments were relatively minor in every size fraction. Apparently, the presence of a magnetic grid minimized the effects of magnetizing and demagnetizing treatments.

Optimum flotation results are obtained at optimum aeration rates (Arbiter, 1962). The presence of a gridwork together with a magnetite coating of about 12.7 mm (0.5 in.) in thickness restricts the apparent escape velocity of particle-bubble aggregates through the gridwork. In fact, a 25.4-mm (1-in.) wide gridwork reduces the flotation area by 20%, and with a 12.7-mm- (0.5-in.-) thick magnetite coating on the grid, the area would be further reduced by an additional 20%, equivalent to a loss of the flotation area by as much as 40%. Increased turbulence may adversely affect the stability of particle-bubble aggregates, even though the magnetite coating did not appear to interfere with flotation. Alternatively, increased turbulence may loosen the flocs and occluded middling particles released, thereby improving the selectivity of separation. A few cursory tests indicated that rounding the

sharp corners of the rectangular-shaped magnetic sheets lowered the magnetite uptake by about 30%. It becomes of interest to study the effects of larger opening size of the gridwork and rounding of the corners of magnetic sheets, as well as of aeration rates on metallurgical results.

Conclusions

- The application of a magnetic field in the form of a gridwork with magnetic sheet strips depressed magnetic particles, thereby improving iron recoveries.
- Iron recoveries to the cell product increased with an increasing number of magnetic sheets.
- Test results expressed in the form of grade-recovery curves clearly indicated that the selectivity of separation improved with an increasing number of magnetic sheets to eight layers.
- Major losses of iron units in froth products were in the -25-μm (500-mesh) fraction, and the application of a magnetic field decreased the flotation of fine magnetite particles, thereby improving the selectivity of separation.
- Magnetite coated the gridwork to a thickness of about 12.7 mm (0.5 in.), but the coating did not interfere with flotation. It becomes of interest to explore a means of reducing the amount of magnetite uptake.
- Magnetic field strengths at the center of each opening were decreased by as much as 50% by the magnetite coating, but this decrease had no apparent effect on flotation results.
- In the presence of a magnetic field in the flotation cell, the "as-received" sample was sufficiently magnetized and no further benefit was gained by magnetizing treatment.
- Demagnetizing of the "as-received" sample led to somewhat lower selectivity of separation, though its effect was minimal due to the action of the magnetic field of the gridwork.
- The use of a nine-opening square grid was shown to provide a useful guide in designing the gridwork suitable for estimating the magnetic field necessary in larger commercial flotation cells.

References

Arbiter, N., and Harris, C.C., 1962, "Flotation machines," *Froth Flotation, 50th Anniversary Volume*, SME/AIME, pp. 347-364.

Ersayin, S., and Iwasaki, I., 2002, "Magnetically enhanced hydroseparators," Preprint 02-190, 2002 SME Annual Meeting, Phoenix, Arizona.

Seetharama, V.N., Malicsi, A.S., and Iwasaki, I., 1991, "Effect of magnetic fields in the flotation of magnetic concentrates," in *Investigation into Production of Iron Ore Concentrates with Less Than 3 Percent Silica from Minnesota Taconites*, Final Report to the State of Minnesota and the American Iron and Steel Institute, Mineral Resources Research Center, University of Minnesota, Minneapolis, Minnesota, 30 pp.

Sonolikar, R.L., Mandlekar, V.A., and Gaidhani, S.B., 1988, "Effect of magnetic field on column flotation of ore containing magnetic content," in *Column Flotation '88*, K.V.S. Sastry, ed., SME Annual Meeting, Jan. 25-28, 1988, Phoenix, Arizona.

Wu, C., Benner, B., and Bleifuss, R.L., 1995, The flotation of taconite in a magnetic field, *Proceedings, Minnesota Section SME 68th Annual Meeting*, Center for Professional Development, University of Minnesota-Duluth, Duluth, Minnesota, pp. 245-256.

Exhibit E

Final Report

MAGNETIC FIELD APPLICATION IN HYDROSEPARATORS

COLERAINE MINERALS RESEARCH LABORATORY

April 25, 2001

CONFIDENTIAL

By Iwao Iwasaki
Iwao Iwasaki
Senior Research Associate
Endowed Taconite Chair

By Salih Ersayin
Salih Ersayin
Program Director
Concentrator Modeling and Simulation

CMRL/TR-01-03
NRRI/TR-2001/13

Project #5601104 & 5698106

Sponsored by the Permanent University Trust Fund and Endowed Taconite Chair

University of Minnesota – Duluth
Natural Resources Research Institute
5013 Miller Trunk Highway
Duluth, Minnesota 55811

Coleraine Minerals Research Laboratory
P O Box 188
One Gayley Avenue
Coleraine, Minnesota 55722

MAGNETIC FIELD APPLICATION IN HYDROSEPARATORS

Abstract: A pilot plant hydroseparator with a magnetic field distribution device was tested on a magnetic taconite plant sample. The device is easy to fabricate and may be readily retrofitted to existing hydroseparators. The effects of feed flowrates, % solids, magnetic field strengths, demagnetizing of and the degree of magnetizing of the test sample were investigated. Magnetizing treatment of the sample in combination with the magnetic field distribution device allowed substantial increase in upward velocities of overflow water with a minimal loss of magnetite particles, indicating hydroseparator capacities could be increased and the grades of underflow products improved.

INTRODUCTION

Hydroseparators are widely used in magnetic taconite processing plants on the Mesabi Iron Range for removing fine siliceous gangue particles. In order to minimize magnetic iron losses, the feed to hydroseparators is magnetized to form flocs, and the upward velocity of overflow water must be carefully controlled. However, the formation of highly flocculated conditions will mechanically trap high-silica middlings as well as free silica particles in magnetite flocs. An increase in the upward velocity of overflow water loosens the flocs and helps to liberate the mechanically trapped siliceous gangue, but fine magnetite particles will also be released from the flocs and lost in the overflow.

Roe (1953) tested a laboratory classifier tube of 1.80 inch ID with a magnetic field imposed using a DC electromagnet coil near the top of the tube. The flux density was varied from 5 to 300 gauss at the internal surface of the tube wall. He reported that high-silica middlings along with free silica particles can be removed by careful control of magnetic field and water supply. While an electromagnet may be used in a laboratory separator, its use in commercial hydroseparators poses a problem.

The purpose of this investigation was to test the use of a magnetic gridwork in applying a magnetic field within a 3-foot diameter pilot scale hydroseparator. The magnetic field was applied by using a gridwork of magnetic sheets. Field strength was varied by changing the opening size of the gridwork, and the width and number of magnetic sheets on the grid. The effects of a magnetic field, demagnetization–magnetization, and the upward velocity of overflow water were investigated.

MAGNETIC GRIDWORK DESIGN

The simplest of regular patterns for gridwork would be either squares or hexagons. A square pattern was selected as it will be easier to construct and structurally stronger. In Progress Report No. 1, dated August 10, 2000, magnetic field strengths of square frames, fabricated from 1/32-inch thick steel sheet were determined. The frames consisted of either ¼- or ½-inch wide strips, with 4, 5 or 6-inch openings in inside dimensions, and magnetic sheets of ¼-inch in thickness cut to ¼- or ½-inch wide strips were placed over the frames. The field strengths were shown to be at minimum at the center of the squares, and the field strength minima at center increased linearly

with an increasing number of layers; the smaller the opening, the higher the field strengths; and the wider the magnetic strips, the stronger the field strengths.

The field strengths in a multi-opening grid work were also investigated by constructing 9-opening square frames of ½-inch strips with 6-inch openings. The field strengths at the centers of the middle, side and corner squares, measured as a function of the number of layers, showed that the field strengths were about twice as high at the center of the middle opening of 9 squares as compared to those of a single square.

To investigate how the field strengths might be affected beyond 9-opening square frames, a gridwork of the size that will fit inside a 3-foot diameter hydroseparator with 6-inch openings of ½-inch magnetic sheet strips was constructed. There were 32 openings as shown in Figure 1. The field strength minimum in each opening was measured as a function of the number of layers of magnetic sheets. Typical values of field strengths of a 4-layer grid are included in the figure. As the openings in the periphery are smaller than the 6"x6" squares, the field strength minima in smaller openings are seen to be higher. Those closer to the 6"x6" squares are somewhat lower as there are no magnetic sheets on the outside. The average values of the 16 openings in the center were virtually identical to those of the center squares in a 9-opening frame. Such an observation suggests that the scale-up of the gridwork may be made by determining the field strengths of the center square of 9-opening frames.

When the gridwork was installed in the 3-foot hydroseparator, however, a feed pipe, wash water pipes and rake shaft had to be installed through the gridwork, and the presence of a steel pipe or rod in a square lowered the field strength. Either one or two additional magnetic sheet strips had to be placed over the frame around the steel pipes and rods to compensate for the field strengths. Figure 2 shows the average field strengths of 16 openings, together with their standard deviations, inside the hydroseparator as a function of the number of layers of magnetic sheets. The field strengths are seen to increase not linearly, but monotonically with the number of layers of magnetic sheets.

HYDROSEPARATOR OPERATION

Test Setup

A schematic diagram of the test setup is shown in Figure 3. A 3-foot diameter Dorr-Oliver SiphonSizer Model D-0 was used for the tests in which a gridwork was installed 8 inches below the overflow lip. Feed was introduced from a 400-gallon sump via a magnetizing-demagnetizing coil and a constant head tank. Feed was introduced into the hydroseparator through a feed well pipe, 3" in diameter, with its end located 20 inches below the overflow lip close to the rake shaft. The feedrate to the hydroseparator was controlled with a manual valve installed below the constant head tank. Feedrates were chosen to cover the upward velocities of overflow water in operating plants of 3 to 3.5 mm/sec, which corresponded to 31 to 36 gpm in the present setup. Hence, most of the tests were run at feed rates of 30 and 50 gpm to cover the range in practice. The hydroseparator was operated so that the underflow was controlled to operate in the range of 60 to 65% solids manually using a pinch valve, and the amount of solids reporting to the overflow was determined. The magnetizing coil, 12" in OD and 7" in ID

with a height of 7", was used either as a demagnetizing unit by applying 220 volt AC, or as a magnetizing coil by applying DC from a rectifier.

Figure 4 shows the magnetic field strengths at the center of the coil plotted as a function of DC current applied. Most of the tests were run at 335 gauss, following plant operating conditions. Figure 5 shows a photograph of the test setup. Figure 6(a) shows the gridwork with 6 layers of magnetic sheet strips, installed 8" below the overflow lip inside the hydroseparator. Figure 6(b) shows the gridwork after a test. The magnetic strips were coated with magnetite particles, approximately ½" thick, which amounted to about 2% of the sample circulating in the system when the initial slurry was set at 30% solids, containing 1300 lbs. of the solids (dry basis).

Test Materials

Two batches of plant hydroseparator samples were received from the U.S. Steel Minntac plant. The first batch was received in ten 55-gallon drums with a net solid weight of approximately 4,000 lbs. on November 6, 2000. The head and screen analyses are given in Table 1. Magnetic iron contents (hereinafter referred to as 'mag Fe') in the table were determined using a Satmagan magnetic balance. This sample was used in exploratory and preliminary tests to Test No. 67. The second batch was received in six 55-gallon drums with a net solid weight of approximately 2,400 lbs. on February 1, 2001. The head and screen analyses are given in Table 2. This sample was used in tests to delineate the effects of the number of magnetic sheets in the magnetic gridwork, demagnetization-magnetization, and a range of flowrates and percent solids.

Exploratory Series of Tests

In an exploratory series of tests, the bulk hydroseparator feed sample received from an operating plant (dated November 6, 2000) was used directly. Initially, the magnetic grid was noted to prevent the loss of magnetic iron from overflow quite effectively, but it soon became apparent that the sample became fully magnetized by repeatedly passing through the magnetizing coil. Magnetic iron in the overflow products decreased to well below 1% irrespective of whether the magnetic grid was present or not and also whether the flowrate was 30 or 50 gpm. The results of these tests are summarized in Appendix I.

Preliminary Series of Tests

Initially, it was planned to investigate the effect of pulp density by varying the % solids of the feed to the hydroseparator at 15%, 20% and 25% in an attempt to cover the plant conditions. The results in this phase of tests are summarized in Appendix II. The test program was initiated with a 15% solid slurry. With an 'as received' sample, there was a substantial loss of magnetic iron to the overflow at a feed rate of 50 gal/min in the absence of a magnetic grid (Test No. 51). Turning on the magnetic coil at 50A (335 gauss) decreased the magnetic iron in the overflow to 4% (Test No. 52). By turning the magnetic coil off and on, the magnetic iron loss to the overflow increased and decreased, but the trend was seen to be a gradual decrease as the process was

repeated, indicating that the magnetite particles were getting more strongly magnetized. Hence, it was thought that full demagnetization was needed ahead of each test in order to use the same sample repeatedly in the test program.

The time required to fully disperse the suspension was estimated by calculating the residence time of the slurry circulating from the sump via the magnetizing coil, connected to an AC power source, and back to the sump. With 400 gallons of the slurry in the sump at a circulating rate of 50 gal/min, the residence time would be 8 minutes, assuming perfect mixing in the sump. Hence, circulation of the pulp three times the residence time, or 24 minutes, at this circulation rate, would expose essentially all the particles in the slurry to demagnetizing action. To ensure full demagnetization of the slurry, the slurry was circulated for 30 minutes prior to turning on the DC current of 50A to the magnetizing coil.

With a slurry after a demagnetizing treatment, much of the demagnetized magnetite particles were observed to be lost to the overflow in the absence of the magnetic grid (Test No. 58: 45% mag Fe in the overflow), but magnetizing of the slurry lowered the mag Fe in the overflow to 1.6% (Test No. 59). When a magnetic gridwork was installed with 6 layers of magnetic sheets (69 gauss), the mag Fe in the overflow was lowered to 1.3% even with a demagnetized feed (Test No. 63). When the DC coil was turned on, the mag Fe was lowered to 0.6% (Test No. 64), indicating that the magnetic gridwork effectively blocked the flocculated magnetic iron particles from overflowing.

During these preliminary tests, it was noted that the pulp densities of the feed to the hydroseparator were decreased by 30 to 40% from the initial feed pulp density. This puzzling behavior was examined by making a material balance of solids in the sump at an initial pulp density and of solids in circulating feed, hydroseparator overflow and underflow products, and the volume of the hydroseparator. From this calculation, it was estimated that nearly 80% of the solids in the original feed material was accumulated as flocculated sediments in the hydroseparator. It was thus concluded that the marked decreases in the pulp densities of circulating feeds during the tests could be attributed to this accumulation. Another puzzling behavior in this series of tests was the wide variation in %Fe in the circulating feeds ranging from 49% to as high as 61% in some tests, while the original feed material analyzed 54.3% Fe. Apparently, the manner in which the sediment in the hydroseparator flocculates and accumulates varied depending on whether the feed was demagnetized or magnetized. In fact, the circulating feeds of demagnetized samples were invariably low in %Fe.

Test Results at 25% Solids

Based on these observations, the initial pulp density was selected to be 25% solids, anticipating that the pulp density may settle to about 20%, and the flowrate was fixed at about 50 gpm. The test procedure was standardized to demagnetize for 30 minutes first, then the DC coil was turned on, and timed samples of feed, overflow and underflow were taken at 8, 16 and 24 minutes to see how many residence times may be needed to reach equilibrium. Then the DC coil was turned off and again timed samples at 8, 16 and 24 minutes were taken to see how the flocs were re-dispersed. Details of the results are given in Appendices III to V.

When a gridwork with 6 magnetic sheets was in place, the overflow of the demagnetized sample at 50 gpm analyzed 1.3% mag Fe. After the DC coil was turned on, mag Fe in the overflow remained below 0.5% whether the DC coil was on or off (Tests No. 68 to 70). When the flowrate was lowered to 30 gpm, mag Fe in the overflow remained well below 1% whether the feed was demagnetized or magnetized (Tests No. 71 to 73), indicating that the magnetic gridwork effectively stopped the overflow of magnetite particles when the rising current velocity was low. Here again, the initial pulp density of the circulating feed decreased by 37 to 46%, when it reached steady state conditions.

An increase in the initial pulp density to 28% solids, when a gridwork with 6 layers of magnetic sheets was in place, produced essentially the same results for mag Fe in the overflow, less than 1% when the DC coil was on. Decreases in the initial pulp densities of the circulating feeds were more pronounced than before, ranging from 52 to 59% (Tests No. 74 to 79).

For comparison, all the magnetic sheets were removed and tests were repeated at an initial pulp density of 25% solids (Tests No. 80 to 85). The mag Fe losses were high, particularly when the slurry was demagnetized. When the magnetic coil was turned on, the mag Fe in the overflow decreased with time, tending towards leveling out after three times the average retention time of 24 minutes (0.18% mag Fe). After the magnetic coil was turned off, the mag Fe increased with time as the slurry circulated in the system (0.31% mag Fe). The rate of increase was more pronounced at the higher flowrate of 50 gpm (2 to 3.7% mag Fe).

Effect of Field Strengths in the Gridwork

Based on the preliminary series of tests, it was concluded that the mag Fe losses into the overflow are strongly dependent on demagnetizing-magnetizing treatment, the magnetic field strengths of the gridwork, and flowrates. Accordingly, it was decided to fix the feed pulp density at 30% solids, and to vary the magnetic field strengths by changing the number of layers of magnetic sheets on the gridwork from none to 6 and by testing at feed rates of 30 and 50 gpm, and collecting the feed, overflow and underflow data on a fully demagnetized feed. This was followed by magnetizing with a coil current of 50A DC and sampling at 8, 16 and 24 minutes. Then the effect of turning off the magnetizing coil was studied by sampling again after 8, 16 and 24 minutes to see how the magnetically flocculated suspension re-dispersed. All the test results are presented in Appendices VI to X. The sequence of the tests was, (1) no magnetic sheet on gridwork first to establish the base condition, (2) the highest magnetic field strength of 6 layers of magnetic sheets to see how much effect the highest field strength had, then (3) the number of magnetic sheets was decreased until the effect of magnetic field became negligible. As it turned out, the effect remained significant even down to one layer of magnetic sheet. In the present section, the relevant data were extracted from the Appendices section and summarized for discussion.

With a demagnetized feed, particularly in the absence of a magnetic field and at high feed rate, much of the feed was lost in the overflow with little or no accumulation in the hydroseparator. As the DC coil was turned on, the magnetite particles flocculated

and the amount of overflow losses became notably less, which took about 24 minutes to reach a new value of mag Fe.

As the DC coil was turned on, mag Fe decreased with time, reaching steady states in about 24 minutes, as expected. When the magnetic field of the gridwork was high and flowrate was low (30 gpm), the time required for mag Fe to reach steady states was shorter, and often 16 minute and 24 minute samples showed about the same mag Fe. When the DC coil was turned off, mag Fe in the overflow, in general, tended to increase by re-dispersion of magnetic flocs.

Table 3 shows the effect of magnetizing time on size analyses of overflow products when the feedrate was 31 gpm and the magnetic grid was 1 layer of magnetic sheet (14 gauss). These tests were selected because mag Fe showed a wider spread than when the magnetic grid had more layers of magnetic sheets. As the DC coil was turned on, mag Fe decreased in every size range. Yet the ratio of mag Fe in a –500 mesh fraction to the respective composite analysis tends to decrease, suggesting that the fine fraction tended to become more strongly flocculated.

Table 4 shows the effects of magnetic field at a feed rate of 30 gpm on demagnetized feed, magnetized feed with DC coil on for 24 minutes, and after DC coil was off for 24 minutes, summarized from Appendices VI to X. Even with the demagnetized feed, one layer of magnetic sheet (14 gauss) already blocked the magnetite particles effectively, but 6 layers (69 gauss) were needed to lower the mag Fe to below 1%. In the case of magnetized feed, whether the magnetizing coil is on or off, even one layer of magnetic sheet lowered mag Fe to below 1% with mag Fe losses of less than 0.1%. The underflow grades in most cases were above 60% Fe.

Table 5 shows similar results at a feed rate of 50 gpm. At this high feed rate on a demagnetized feed, the losses of mag Fe into overflow were appreciably higher than before, with 66% of the feed reporting to the overflow (49% mag Fe). However, six layers of magnetic sheets lowered mag Fe to below 1%. Magnetized feed must have been well flocculated, and, here again, mag Fe in the overflows even with one layer of magnetic sheet (14 gauss) were well below 1%, with mag Fe losses below 0.1%. The grades of underflows were over 61% in most cases. These observations suggest that the overflow rates, or the upward velocities of overflow water, may be increased appreciably over the current practice. In addition, an increase in overflow rates, particularly with magnetized feeds, appeared to help dislodge the mechanically trapped siliceous gangue particles from flocs.

Effect of Feed Rates

In view of the results with 6 layers of magnetic sheets on demagnetized feed samples in Tables 4 and 5, which gave less than 1% mag Fe in the overflow, the feed rates were increased to 60, 70 and 80 gpm. The feed rate of 80 gpm was the maximum attainable with the current test setup. It was hoped that if the magnetic gridwork could block the magnetite particles even with demagnetized feed, the occlusion of fine siliceous gangue in magnetically flocculated aggregates may be prevented. These tests were also intended to ascertain how much the hydroseparator capacity might be increased. The results are summarized in Table 6.

Contrary to the expectations from the previous results, mag Fe in the overflows with the demagnetized feeds was higher than 1% and increased with increasing feed rates, both with 6 and 4 layers of magnetic sheets (69 and 50 gauss, respectively). With 4 layers of magnetic sheets, the losses of mag Fe to the overflow were higher than those with 6 layers, as expected. However, magnetizing of the feed at 50A DC markedly lowered the mag Fe losses. The underflow grades attained in excess of 61% Fe, indicating that even with magnetically flocculated suspensions, the occluded siliceous gangue particles must have been dislodged at higher flowrates and removed to the overflows.

Effect of Magnetizing Current

The foregoing results using a fully demagnetized feed and those magnetized at 50A DC, particularly at high feed rates, showed that the formation of magnetized floccules prevented the losses of fine magnetite particles. In an attempt to explore the effect of magnetization, a series of tests was carried out at a feed rate of 70 gpm, varying the DC coil currents from 10 to 50A when the magnetic gridwork was coated with 4 layers of magnetic sheets (50 gauss). The results are summarized in Table 7. The optimum range of magnetic current appeared to be 20 to 30A, which gave less than 1% mag Fe in the overflow, with the underflow analyzing 62 to 63% Fe.

The overflow products at different magnetizing currents when the feedrate was 70 gpm were screened, and the effect on different size fractions was examined. Results are given in Table 8. Here again, mag Fe decreased in every size range indicating that increasing amounts of locked particles were prevented from overflowing.

In an attempt to characterize the degree of flocculation, the settling velocities of feed suspensions at different magnetizing currents were determined. The flocculation tests were carried out by using a 1,000-mL graduated cylinder. After introducing a slurry to near 1,000 mL mark, the total volume was adjusted to the 1,000 mL mark, the cylinder was inverted 5 times to mix the suspension thoroughly, set it down and the descent of the mudline was recorded as a function of time. The settling velocities thereby determined are plotted in Figure 7 as a function of the magnetizing current. It is evident that the settling velocity increased linearly with the magnetizing current, indicating that the floc sizes increased with increasing magnetizing current.

CONCLUSIONS

1. Magnetic gridwork effectively stops the overflow of magnetic particles. However, mag Fe in overflow products of fully demagnetized feed analyzed over 1% at all levels of magnetic fields, although some of the tests with 6 layers of magnetic sheets (69 gauss) were less than 1%.

2. Magnetizing of feed samples with a coil current of 50A DC (335 gauss) effectively flocculates the samples, yet in the absence of magnetic field, mag Fe in the overflow products remained above 2% even at 30 gpm (upward velocity of overflow water of about 2.3 mm/sec). At 50 gpm (upward velocity

of overflow water of about 3.6 mm/sec), mag Fe in the overflow products increased beyond 6%.

3. With the magnetic gridwork in place, feed samples magnetized with a coil current of 50A (335 gauss) invariably produced overflow products analyzing less than 1% mag Fe regardless of the number of magnetic sheets on the gridwork (14 to 69 gauss), or the upward velocities of overflow water (2.3 to 3.6 mm/sec). The mag Fe loss to overflow in all cases remained less than 0.1%.

4. With a magnetic gridwork composed of 4 layers of magnetic sheets (50 gauss) in place, the upward velocities of overflow water may be increased to as high as 5.8 mm/sec with feed samples magnetized with a coil current of 50A (335 gauss) without raising the mag Fe in overflow products above 1%.

5. With the magnetic gridwork of 4 layers of magnetic sheets (50 gauss) in place and at an upward velocity of overflow water of 5.4 mm/sec, magnetization of feed samples with coil currents of 20 to 30 A (135 to 197 gauss) appeared to give the optimum results. Overflow products analyzed 0.8 to 0.9% mag Fe with mag Fe losses of less than 0.2%, and the underflow grades were in excess of 62% Fe.

6. The present investigation was carried out in a closed circuit. It is desirable to test in an open circuit to simulate plant conditions and to ascertain the effects of increased % solids, the behavior of sedimented flocs in the hydroseparator, and also to test higher overflow rates to see if hydroseparator capacities may be increased and underflow grades may be improved further.

REFERENCES

Iwasaki, I., and Wu, C., 2000, Magnetic field application in hydroseparators and flotation cells, Progress Report No. 1, Coleraine Minerals Research Laboratory, Natural Resources Research Institute, University of Minnesota-Duluth, CMRL/TR-0012, NRRI/TR-2000/38, 21p.

Roe, L.A., 1953, The magnetic reflux classifier, Mining Engineering, Vol. 5, No. 3, pp. 312-315.

Roe, L.A., 1957, *Iron Ore Beneficiation,* Minerals Publishing Company, Lake Bluff, Illinois, p. 159

Table 1. Head and Screen Analysis Data on Minntac Plant Hydroseparator Feed Sample (11-06-00) Used in Exploratory and Preliminary Tests

(a) Head analysis results

% Fe	% SiO_2	% Mag Fe
54.3	20.62	49.90

(b) Screen analysis results

Size, mesh	% Weight	% Fe	% Mag Fe
100	1.1	30.5	23.31
150	5.7	24.2	13.90
200	7.6	35.2	13.68
270	15.8	53.3	56.21
325	4.1	62.8	57.82
400	8.7	59.8	55.95
500	13.1	61.1	57.98
-500	43.9	58.8	54.90
Composite	100.0	54.3	49.90

Table 2. Head and Screen Analysis Data on Minntac Plant Hydroseparator Feed Samples (02-01-01)

(a) Head analysis results

% Fe	% SiO_2	% Mag Fe
57.1	17.29	53.01

(b) Screen analysis results

Size, mesh	% Weight	% Fe	% Mag Fe
100	0.2		
150	3.9		
200	7.6		
270	9.0		
325	6.9		
400	5.6		
500	13.7		
-500	53.1		
Composite	100.0		

Table 3. Effect of Magnetization on Size Analyses of Overflow Products

Feed: 30% solids (initial); Magnetic grid: 1 layer; Magnetic coil: 50A; Feed rate: 31 gpm

Size, mesh	Test 110 (demagnetized)				Test 111A (magnetized 8')				Test 111B (magnetized 16')				Test 111C (magnetized 24')			
	% Wt.	Overall % Wt.	% Fe	% Mag Fe	% Wt.	Overall % Wt.	% Fe	% Mag Fe	% Wt.	Overall % Wt.	% Fe	% Mag Fe	% Wt.	Overall % Wt.	% Fe	% Mag Fe
100									0.1				2.3	0.06	15.8	1.09
150	0.1	0.01			0.7	0.06	17.4	4.74	3.9	0.12	16.0	1.28	5.0	0.14	16.1	0.70
200	0.1	0.01			0.6	0.05	16.8	3.50	1.8	0.05	15.9	1.41	2.2	0.06	14.8	1.23
270	1.8	0.2	10.4	3.47	1.9	0.2	10.6	1.68	2.2	0.07	13.0	1.00	2.4	0.06	14.4	0.96
400	10.9	1.5	10.6	1.05	8.5	0.7	9.8	1.08	7.1	0.21	10.2	0.94	7.2	0.2	10.4	0.70
500	19.0	2.6	14.9	1.90	16.7	1.4	14.2	1.34	14.8	0.44	13.4	0.74	15.0	0.4	13.2	0.53
-500	68.1	9.2	18.5	4.40	71.6	6.0	16.8	2.55	70.1	2.1	16.2	1.30	65.9	1.8	16.2	0.89
Composite	100.0	13.5	16.8	3.54	100.0	8.4	16.2	2.23	100.0	3.0	15.3	1.19	100.0	2.7	15.2	0.83

Table 4. Effect of Magnetic Field on Demagnetized Feed, Magnetized with DC Coil (50A) On for 24 minutes, and After DC Coil Off for 24 Minutes

30% solids (initial); 30 gpm feed rate

Test No.	Mag Sheet		Circulating Feed % Solids	O'flow rate		O'flow				Un'flow % Fe
	No.	Gauss		gpm	mm/sec	% Solids	% Wt.	Mag Fe	Mag Fe Loss	
Demagnetized										
86	0	0	24.9	25.6	2.5	13.9	40.1	52.47	40.24	56.1
110	1	14	13.7	27.6	2.6	1.5	13.5	3.41	0.96	60.8
107	2	26	12.8	26.4	2.5	1.5	9.4	1.93	0.36	59.6
98	4	50	17.8	23.0	2.2	1.5	4.2	1.13	0.09	57.4
95	6	69	21.0	24.6	2.4	2.0	7.4	0.42	0.06	59.5
Mag Coil On (50A, 24 min)										
87C	0	0	23.7	25.5	2.4	2.9	9.8	2.27	0.42	61.6
111C	1	14	26.2	20.9	2.0	1.5	2.7	0.81	0.04	61.2
108C	2	26	21.3	22.7	2.2	1.6	4.2	0.60	0.05	62.3
99C	4	50	22.2	24.6	2.4	1.7	5.5	1.04	0.11	61.0
96C	6	69	24.6	23.0	2.2	2.2	5.0	0.31	0.03	61.5
Mag Coil Off (50A, 24 min)										
88C	0	0	24.4	24.9	2.4	2.9	8.8	2.00	0.33	61.6
112C	1	14	19.9	24.5	2.4	1.5	5.1	0.67	0.06	61.0
109C	2	26	19.1	24.1	2.3	1.6	5.4	0.46	0.05	61.2
100C	4	50	23.0	24.0	2.3	1.6	6.4	0.59	0.07	60.9
97C	6	69	23.4	23.3	2.2	2.1	5.8	0.36	0.04	61.3

Table 5. Effect of Magnetic Field on Demagnetized Feed, Magnetized with DC Coil (50A) On for 24 minutes, and After DC Coil Off for 24 Minutes

30% solids (initial); 50 gpm feed rate

Test No.	Mag Sheet		Circulating Feed % Solids	O'flow rate		O'flow				Un'flow % Fe
	No.	Gauss		gpm	mm/sec	% Solids	% Wt.	Mag Fe	Mag Fe Loss	
Demagnetized										
89	0	0	22.1	42.1	4.0	15.7	66.0	49.18	64.94	54.7
113	1	14	11.4	42.1	4.0	2.2	14.7	14.11	4.17	59.9
104	2	26	17.1	35.9	3.4	2.0	7.0	2.12	0.28	60.7
101	4	50	15.2	39.3	3.8	1.9	10.9	1.56	0.33	59.9
92	6	69	17.6	37.5	3.6	2.8	(20.8)	0.70	0.32	63.2
Mag Coil On (50A, 24 min)										
90C	0	0	17.8	39.7	3.8	3.5	14.7	5.90	1.77	54.7
114C	1	14	16.5	39.1	3.8	1.8	6.8	0.78	0.10	59.6
105C	2	26	17.7	36.8	3.5	2.1	8.0	0.66	0.10	61.5
102C	4	50	20.2	35.8	3.4	1.9	6.9	0.54	0.07	62.9
93C	6	69	22.8	30.5	2.9	2.6	6.4	0.17	0.02	61.8
Mag Coil Off (50A, 24 min)										
91C	0	0	20.7	37.5	3.6	6.6	21.4	31.51	12.68	61.5
115C	1	14	13.7	42.2	4.1	1.8	10.4	0.89	0.18	61.1
106C	2	26	16.2	37.7	3.6	2.0	9.0	0.53	0.09	62.0
103C	4	50	18.9	38.0	3.6	1.9	9.1	0.59	0.10	61.0
94C	6	69	21.4	33.2	3.2	2.7	9.4	0.46	0.08	60.5

Table 6. Effect of Feed Rates Using Demagnetized Feed and Preliminary Tests with Feed Magnetized Through DC Coil at 50A

30 % solids (initial)

Test No.	Feed rate gpm	Circulating Feed % Solids	O'flow rate		O'flow				Un'flow % Fe
			gpm	mm/sec	% Solids	% Wt.	Mag Fe	Mag Fe Loss	
Magnetic grid: 6 layers (69 gauss) Demagnetized									
116	43.4	15.3	33.7	3.2	1.5	8.3	1.61	0.25	61.4
117	60.7	14.8	44.1	4.2	1.7	9.3	1.89	0.33	61.9
118	70.1	14.4	53.8	5.2	1.9	10.3	1.82	0.35	61.8
119	80.4	13.2	60.2	5.8	2.0	14.0	2.05	0.57	62.9
Magnetic grid: 4 layers (50 gauss) Demagnetized									
120	41.2	16.2	33.0	3.2	1.4	7.4	2.06	0.29	60.1
121	62.2	16.7	45.9	4.4	1.8	8.0	3.09	0.46	60.4
122	70.4	14.8	56.3	5.4	2.0	11.9	3.75	0.88	60.9
Magnetic grid: 4 layers (50 gauss) Magnetized (50A, preliminary)									
123	70.4	16.4	53.2	5.1	1.8	8.2	0.44	0.07	61.1
124	79.7	14.5	59.9	5.8	1.9	9.6	0.85	0.15	61.6

Table 7. Effect of Magnetizing Current of DC Coil

30% solids (initial); Magnetic grid: 4 layers

Test No.	Mag Coil A	Circulating Feed % Solids	O'flow rate		O'flow				Un'flow % Fe
			gpm	mm/sec	% Solids	% Wt.	Mag Fe	Mag Fe Loss	
Feed rate: 70 gpm									
125	AC	13.6	56.8	5.5	2.4	12.9	4.78	1.18	63.3
126	10	15.7	55.3	5.3	2.1	9.9	1.26	0.23	63.7
127	20	15.7	54.6	5.2	2.1	10.8	0.85	0.17	62.9
128	30	14.2	56.9	5.5	2.0	11.1	0.94	0.20	62.0
129	40	14.3	55.9	5.4	1.9	10.9	0.81	0.17	61.3
130	50	14.6	59.5	5.7	2.0	(16.2)	0.81	0.26	61.9
Feed rate: 50 gpm									
131	AC	13.8	38.9	3.7	1.5	8.5	2.68	0.44	59.6
132	50	19.7	34.4	3.3	1.5	6.0	0.50	0.05	61.6
Feed rate: 51.5 gpm									
133	AC	13.8	38.4	3.7	1.7	11.2	1.72	0.36	62.8
134	10	17.7	36.6	3.5	1.6	6.0	0.96	0.10	61.6
135	20	17.4	37.8	3.6	1.6	7.1	0.92	0.12	61.9
136	30	19.4	35.7	3.4	1.6	5.4	0.42	0.04	62.3
137	40	19.2	35.9	3.4	1.5	5.7	0.63	0.06	62.4
138	50	18.2	36.8	3.5	1.5	6.5	0.58	0.07	61.7

Table 8. Effect of Magnetizing Current on Size Analyses of Overflow Products

Feed: 30% solids (initial); Magnetic grid: 4 layers; Feed rate: 70 gpm

Size, Mesh	Test 125 (demagnetized)				Test 126 (magnetized @ 10A)				Test 127 (magnetized @ 20A)			
	% Wt.	Overall % Wt.	% Fe	% Mag Fe	% Wt.	Overall % Wt.	% Fe	% Mag Fe	% Wt.	Overall % Wt.	% Fe	% Mag Fe
100									2.3	0.2	16.3	1.17
150	1.0	0.1	14.7	3.17					1.2	0.1	16.0	1.49
200	3.0	0.4	10.5	2.75	2.0	0.2	11.4	2.46	3.8	0.4	9.3	0.93
270	15.4	2.0	14.0	2.59	12.7	1.3	12.6	1.66	21.8	2.4	7.0	1.08
400	15.6	2.0	17.9	3.36	13.9	1.4	15.6	1.84	14.5	1.6	15.7	0.95
500	17.0	2.2	20.6	5.47	16.0	1.6	17.1	1.29	12.6	1.4	17.0	0.85
-500	48.0	6.2	21.7	5.94	55.4	5.4	18.0	1.92	43.8	4.7	17.1	1.17
Composite	100.0	12.9	19.3	4.82	100.0	9.9	16.7	1.79	100.0	10.8	14.4	1.07

Size, Mesh	Test 128 (magnetized @ 30A)				Test 129 (magnetized @ 40A)				Test 130 (magnetized @ 50A)			
	% Wt.	Overall % Wt.	% Fe	% Mag Fe	% Wt.	Overall % Wt.	% Fe	% Mag Fe	% Wt.	Overall % Wt.	% Fe	% Mag Fe
100	4.4	0.5	16.0	0.66	7.7	0.8	15.4	0.65	4.1	(0.7)	15.8	0.75
150	0.8	0.1	15.0	1.52	1.1	0.1	15.4	1.09	1.2	(0.2)	15.8	1.25
200	2.6	0.3	9.2	0.89	2.6	0.3	9.1	0.70	3.0	(0.5)	8.4	1.18
270	19.7	2.2	12.0	1.06	18.1	2.0	11.9	0.93	18.4	(3.0)	11.9	0.95
400	15.2	1.7	15.1	0.93	15.4	1.7	14.6	0.96	15.9	(2.6)	15.1	1.13
500	13.1	1.5	16.3	1.29	17.0	1.9	15.8	0.93	15.9	(2.6)	15.8	0.82
-500	44.2	4.8	16.7	0.99	38.1	4.1	16.8	0.93	41.5	(6.9)	17.4	1.01
Composite	100.0	11.1	15.2	1.02	100.1	10.9	15.1	0.77	100.0	(16.5)	15.4	0.99

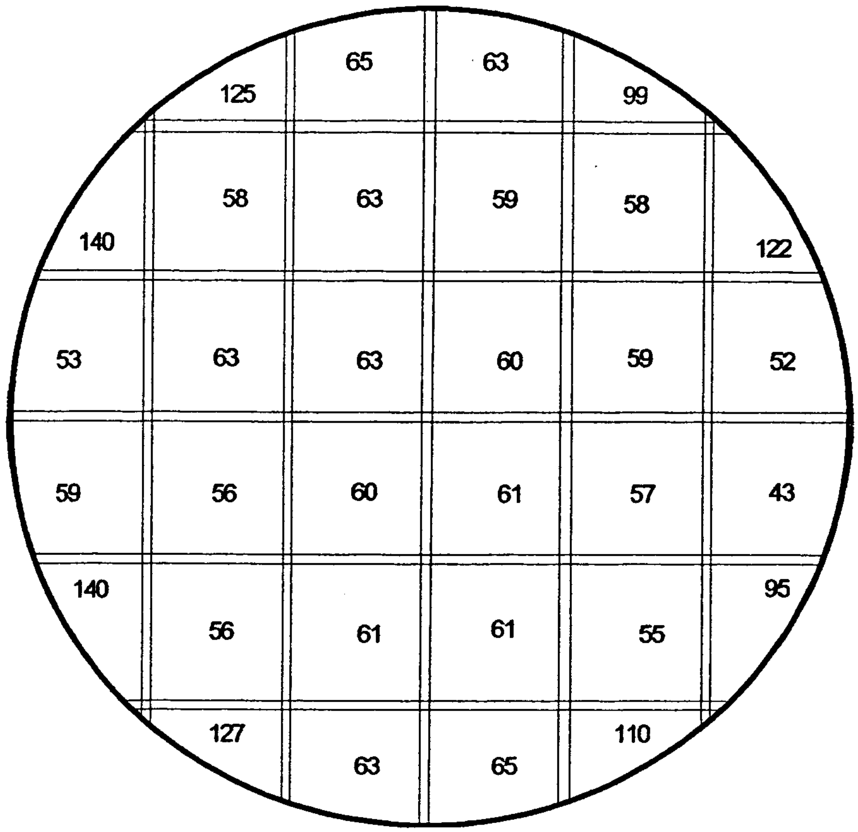

Figure 1. Gridwork frame of ½ inch width with 6-inch openings fabricated to fit inside a 3-foot diameter hydroseparator. The numbers in openings indicate typical values of field strengths of a gridwork with 4 layers of magnetic sheets.

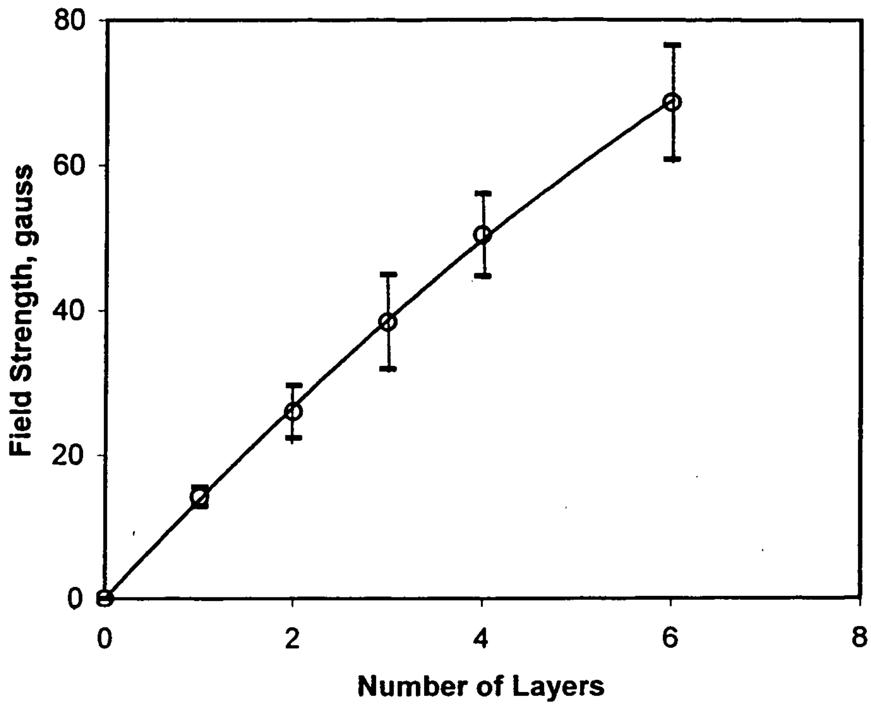

Figure 2. Average field strengths of 16 openings inside hydroseparator as a function of the number of layers of magnetic sheets

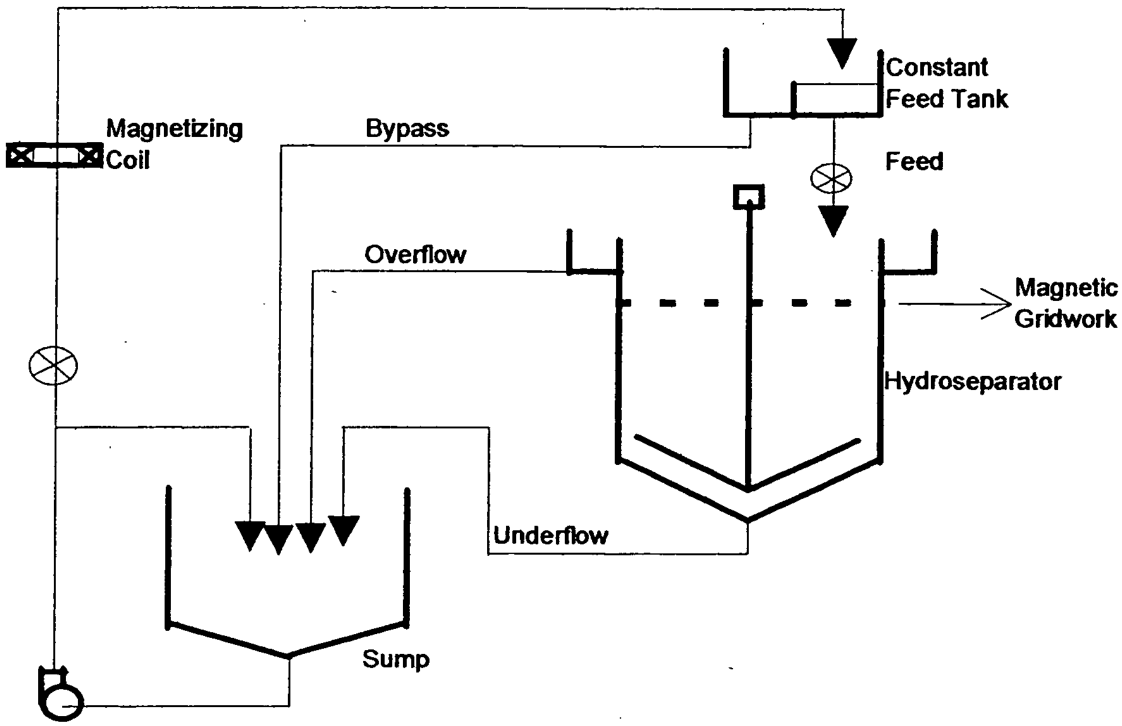

Figure 3. Schematic flow diagram of hydroseparator test setup.

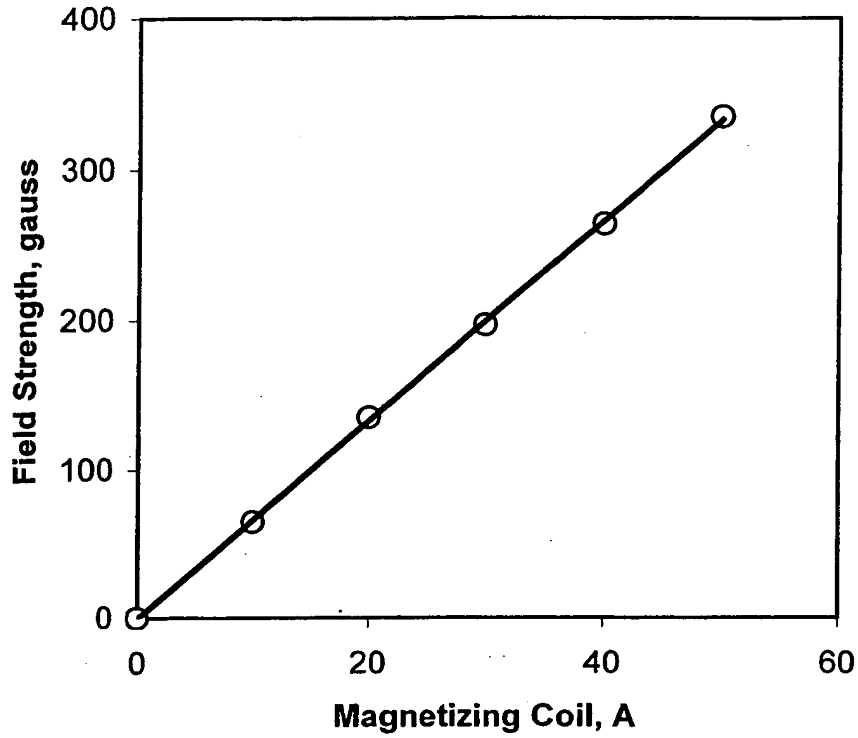

Figure 4. Magnetic field strength of magnetizing coil as a function of DC current applied

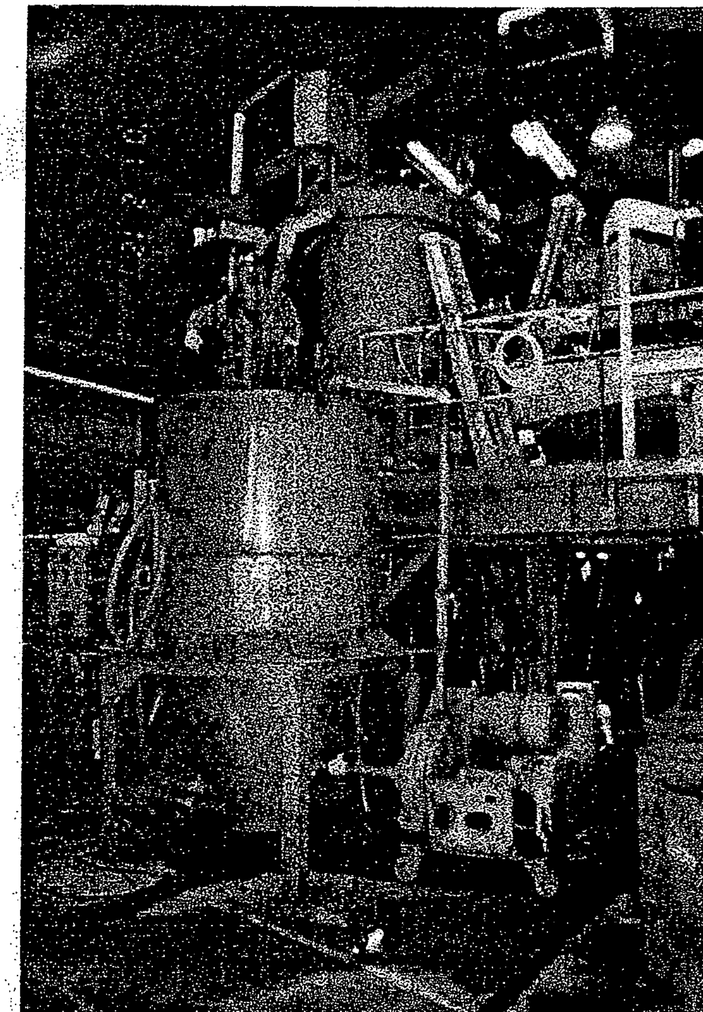

Figure 5. Overall View of Hydroseparator Test Set-Up

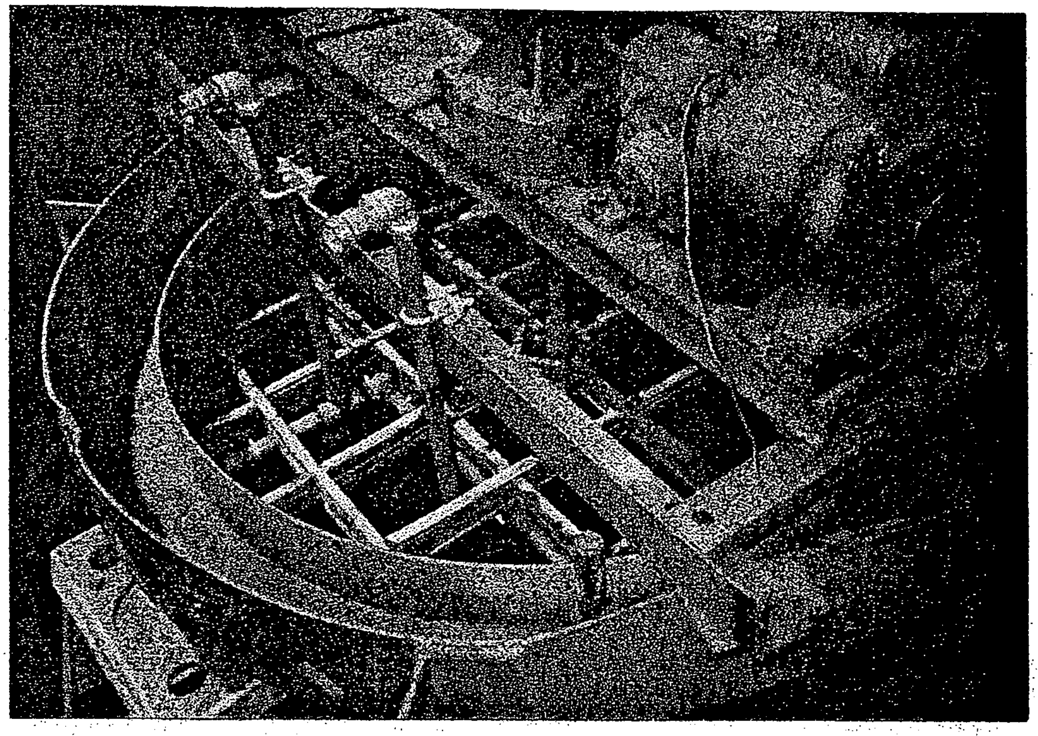

Figure 6(a). Gridwork Inside Hydroseparator

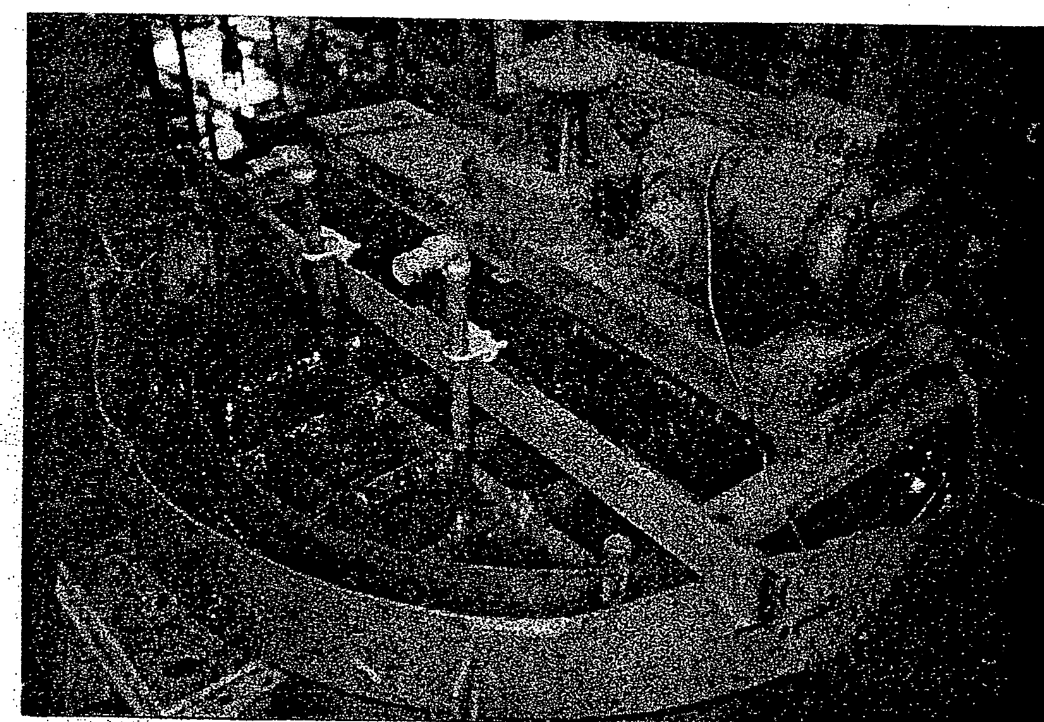

Figure 6(b). Gridwork Coated with Magnetite After Test

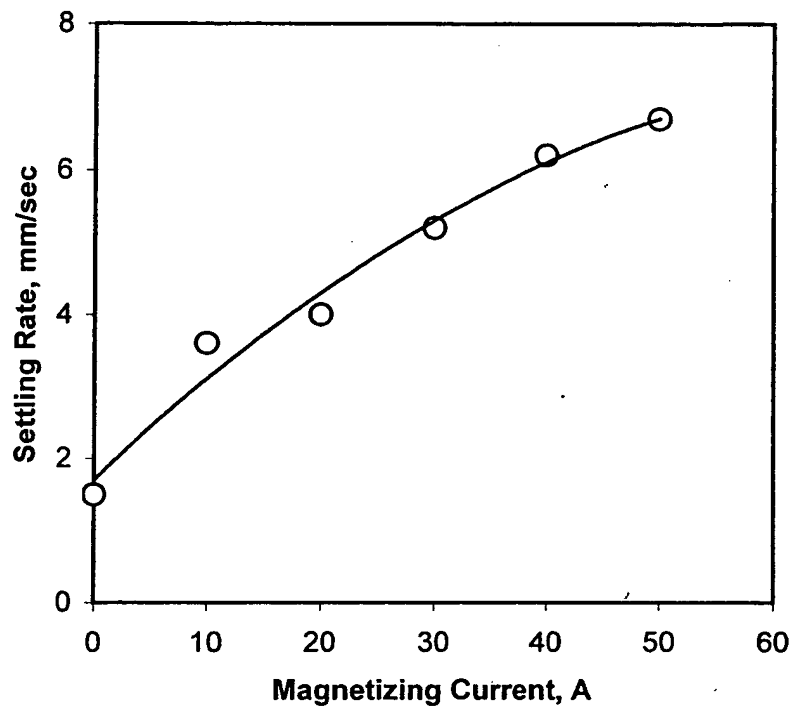

Figure 7. Effect of magnetizing current on settling rates

APPENDICES

I - XII

Appendix I. Summary of Exploratory Test Results on "As Received" Sample

Test No.	% Solids	Mag Coil	Mag Grid	Feed ppm	Feed % Fe	Feed % Mag Fe	Un'flow % Fe	Un'flow % Mag Fe	O'flow % Fe	O'flow % Mag Fe
9	12	Off	None	31.5	49.1	44.17	55.2	51.58	27.7	15.73
10		On		30.5	53.4	48.34	60.4	56.92	15.0	0.63
11		Off		21.5	51.8	46.15	55.9	53.28	20.3	—
12		On		21.5	55.1	50.57	60.6	57.14	15.8	1.63
13		On		9.5	56.4	51.62	59.6	55.88	16.5	0.97
14		Off		9.5	54.2	49.31	57.8	54.03	19.7	5.50
15		On	4	31	56.9	52.76	61.6	59.68	15.4	0.39
16		On	4	22	57.6	53.32	60.6	57.46	15.4	0.26
17		On	4	10	56.9	53.27	59.7	56.40	16.0	0.47
18		Demag	4	10	48.7	44.20	53.2	50.05	16.0	1.65
19		Demag	4	22	49.5	43.81	57.0	53.19	17.1	4.14
20		Demag	4	31	54.0	47.27	55.2	50.93	16.8	3.66
21		On	6	31	57.4	52.20	61.3	55.53	15.8	0.75
22			6	22	59.4	54.60	61.6	57.63	16.1	0.42
23			6	10	60.2	56.37	61.4	57.51	16.3	0.81
24			2	31	57.1	52.96	62.4	60.16	15.4	0.42
25			2	22	56.5	52.78	62.5	59.35	16.0	0.83
26			2	10	56.8	53.17	58.6	55.77	16.0	0.47
27	18		2	47	56.0	50.20	62.5	59.13	18.3	2.47
28			2	31	58.0	53.32	61.9	58.00	16.6	0.53
29			2	24	57.3	53.14	62.0	58.12	16.3	0.78
30			4	44.4	58.3	53.69	60.6	58.93	16.6	1.56
31			4	34.9	57.9	53.17	61.0	56.62	16.2	1.41
32			4	24	58.4	53.61	61.9	58.70	16.1	0.34
33			6	Max	58.8	53.64	61.3	57.05	—	—
34			6	30	59.0	53.58	62.1	58.07	15.1	0.11
35			6	20	60.8	56.83	63.2	59.89	15.8	0.66
36			None	Max	56.9	51.32	61.5	57.10	15.3	0.58
37				30	57.5	52.15	62.2	57.60	15.3	0.50
38				20	58.5	53.40	61.9	57.76	15.9	0.59
39	25			47	56.4	53.14	60.9	57.25	15.1	0.42
40				33.5	56.2	55.85	61.3	58.16	14.6	0.46
41				24.3	58.6	54.31	59.9	56.89	15.7	0.63
42			2	48	58.9	54.05	59.5	56.60	14.6	0.25
43			2	33.8	60.6	57.76	61.4	57.02	14.8	0.57
44			2	22.9	62.6	58.21	61.8	56.96	15.4	0.74
45			4	48	56.6	52.23	62.3	56.21	14.6	0.42
46			4	32.6	57.9	54.77	61.1	56.31	15.0	0.59
47			4	22.8	58.6	55.77	61.9	57.04	15.2	0.48
48			6	48	56.6	52.31	62.8	61.31	14.7	0.50
49			6	37.2	60.0	55.39	59.6	58.00	15.2	0.39
50			6	22.1	56.9	54.29	61.1	56.53	15.7	0.59

Appendix II. Summary of Preliminary Test Results on the Effects of Demagnetizing and Magnetic Grid

Test No.	Mag Coil	Time, min	Feed			Underflow				Overflow			
			% Solids	% Fe	% Mag Fe	% Solids	% Wt.	% Fe	% Mag Fe	% Solids	% Wt.	% Fe	% Mag Fe
Sample: As received Mag grid: None Feed rate: 50 gpm @ 15.2% solids (initial) Circulating feed *: 13.2 ± 1.1% solids													
51	Off		13.2			64.9	78.2			3.5	21.8	37.5	27.86
52	On		11.6			55.9	82.8			2.0	17.2	16.7	3.98
53	Off		14.2			55.3	88.9			2.1	11.1	20.2	6.65
54	On		14.2			56.3	87.9			1.9	12.1	15.4	1.00
55	Off		12.8			58.6	85.8			2.0	14.2	19.6	5.94
Sample: Demagnetized for 30 min Mag grid: None Feed Rate: 77 gpm @ 7.5% solids (initial) Circulating feed *: 4.9 ± 0.5% solids													
56	Demag	5.2				27.3	21.5			4.2	78.5		
57	On	4.5				60.0	56.5			1.9	43.5		
Sample: Demagnetized for 30 min Mag grid: None Feed rate: 52 gpm @ 17% solids (initial) Circulating feed *: 10.3 ± 1.1% solids													
58	Demag	—	10.0			57.0	(90.1)			6.0	(9.9)		45.19
59	On	24	12.2			62.4	90.0			1.7	10.0		1.64
60	Off	"	9.3			55.3	68.4			2.5	31.6		18.13
61	On	"	10.1			54.9	80.9			1.8	19.1		1.01
62	Off	"	10.1			57.8	80.4			2.2	19.6		12.73
Sample: Demagnetized for 30 min Mag grid: 6 layers Feed rate: 52.7 gpm @ 17% solds (initial) Circulating feed *: 10.1 ± 1.3% solids													
63	Demag	—	8.7			59.5	82.3			1.5	17.7		1.30
64	On	24	12.0			62.3	91.1			1.5	8.9		0.58
65	Off	"	9.8			59.3	86.8			1.5	13.2		1.28
66	On	"	10.7			61.6	88.4			1.5	11.6		0.50
67	Off	"	9.1			64.6	56.0			1.4	14.0		1.00

* Circulating feed is the average of % solids of Feed.

Appendix III. Effects of Demagnetizing – Magnetizing on Hydroseparator Performance

Feed: 25% solids (initial)   Magnetic grid: 6 layers

Test No.	Mag Coil	Time, min	Feed			Underflow					Overflow					Loss to O'flow	
			% Solids	% Fe	% Mag Fe	% Solids	Water, gpm	% Wt.	% Fe	% Mag Fe	% Solids	Water, gpm	% Wt.	% Fe	% Mag Fe	Fe	Mag Fe
		Feed Rate: 32.4 gpm															
		Circulating feed *: 15.8 ± 3.1% solids															
71	Demag	30	13.4	52.9	47.23	55.3	5.1	91.7	55.3	49.30	1.2	23.4	8.3	14.7	0.74	2.35	0.14
72A	On	8	13.6	56.9	52.14	61.7	2.9	94.3	60.6	54.83	1.3	22.2	5.7	15.5	0.67	1.52	0.07
72B	On	16	19.2	58.6	53.92	61.0	3.7	94.9	60.9	55.77	1.4	22.0	5.1	16.2	0.58	1.41	0.06
72C	On	24	20.6	59.3	54.51	62.7	5.4	97.0	61.0	55.73	1.3	21.9	3.0	15.7	0.30	0.79	0.02
73A	Off	8	16.7	57.9	53.01	51.5	4.9	94.3	60.5	54.94	1.4	22.1	5.7	16.6	0.20	1.63	0.02
73B	Off	16	13.7	57.2	50.06	59.5	2.3	91.2	60.2	55.06	1.4	23.5	8.8	15.0	0.23	2.35	0.04
73C	Off	24	13.3	56.6	52.28	64.7	2.1	92.6	60.0	55.34	1.4	23.0	7.4	15.8	0.35	2.06	0.05
		Feed Rate: 52.7 gpm															
		Circulating feed *: 13.5 ± 2.0% solids															
68	Demag	30	12.0	54.7	49.53	54.8	3.6	85.1	59.5	54.44	1.8	40.8	14.9	16.7	1.33	4.68	0.43
69A	On	8	11.7	55.4	50.44	65.7	2.7	87.2	60.8	56.41	1.8	40.8	12.8	16.0	0.45	3.72	0.12
69B	On	16	15.1	57.4	53.43	61.4	3.3	87.8	61.1	56.47	1.8	39.9	12.3	16.3	0.26	3.60	0.06
69C	On	24	16.9	57.6	53.53	64.2	4.3	92.0	61.2	56.62	1.8	36.8	8.0	15.2	0.23	2.11	0.04
70A	Off	8	11.7	56.0	50.81	66.5	1.9	83.8	61.1	55.84	1.9	39.6	16.2	15.6	0.45	4.70	0.16
70B	Off	16	12.9	56.1	51.40	63.7	3.9	90.9	59.8	55.97	1.7	38.6	9.1	15.6	0.63	2.55	0.11
70C	Off	24	14.2	56.3	51.15	62.9	2.6	85.9	60.6	55.33	1.8	39.5	14.1	15.6	0.28	4.05	0.08

* Circulating feed is the average of % solids of Feed.

Appendix IV. Effects of Demagnetizing – Magnetizing on Hydroseparator Performance

Feed: 28% solids (initial) Magnetic grid: 6 layers

Test No.	Mag Coil	Time, min	Feed			Underflow				Overflow			
			% Solids	% Fe	Mag Fe	% Solids	% Wt.	% Fe	Mag Fe	% Solids	% Wt.	% Fe	Mag Fe
		Feed rate: 32.5 gpm											
		Circulating feed *: 13.3 ± 1.9% solids											
74	Demag	30	11.4			66.5	90.9			1.1	9.1		1.68
75A	On	8	13.6			62.8	95.2			1.1	4.8		1.29
75B	On	16	11.3			58.3	90.2			1.3	9.8		1.03
76A	Off	8	14.4			64.3	85.0			1.3	15.0		0.78
76B	Off	16	12.8			68.9	92.5			1.2	7.5		0.56
76C	Off	24	16.3			56.5	91.5			1.2	8.5		0.70
		Feed rate: 52.1 gpm											
		Circulating feed *: 11.4 ± 1.3% solids											
77	Demag	30	9.2			58.4	86.1			1.3	13.9		2.04
78A	On	8	13.2			62.5	91.5			1.4	8.5		1.21
78B	On	16	11.3			56.1	89.6			1.4	10.4		0.47
78C	On	24	10.6			68.5	93.5			0.7	6.5		0.78
79A	Off	8	11.2			60.7	90.2			1.4	9.8		0.58
79B	Off	16	12.3			60.5	90.5			1.4	9.5		0.81
79C	Off	24	12.0			57.3	88.4			1.4	11.6		0.60

Appendix V. Effects of Demagnetizing – Magnetizing on Hydroseparator Performance

Feed: 25% solids (initial)   Magnetic grid: 0 layers

Test No.	Mag Coil	Time, min	Feed			Underflow					Overflow					Loss to O'flow	
			% Solids	% Fe	% Mag Fe	% Solids	Water, gpm	% Wt.	% Fe	% Mag Fe	% Solids	Water, gpm	% Wt.	% Fe	% Mag Fe	Fe	Mag Fe
		Feed Rate: 30.9 gpm Circulating feed *: 13.9 ± 1.8% solids															
83	Demag	30	11.1	53.9	47.71	64.4	1.8	76.1	54.6	50.09	3.4	29.8	23.9	48.9	41.73	21.95	20.74
84A	On	8	12.2	55.9	51.66	59.6	2.0	83.5	60.3	55.64	1.9	29.7	16.5	32.0	21.01	9.49	6.94
84B	On	16	15.0	57.2	53.45	63.2	2.5	91.4	60.9	56.53	1.4	28.7	8.6	18.8	4.11	2.82	0.68
84C	On	24	14.0	58.1	52.99	60.1	3.3	92.6	61.2	55.12	1.4	29.2	7.4	17.4	1.27	2.22	0.18
85A	Off	8	15.6	57.3	54.31	59.3	4.4	94.8	60.2	56.23	1.3	27.1	5.2	16.8	1.17	1.51	0.11
85B	Off	16	13.4	56.4	52.85	60.0	2.4	90.3	60.5	55.71	1.3	29.2	9.7	16.9	1.60	2.91	0.31
85C	Off	24	15.9	57.1	52.49	56.3	3.7	92.7	60.0	55.20	1.3	28.0	7.3	16.7	2.16	2.14	0.31
		Feed Rate: 50.6 gpm Circulating feed *: 12.3 ± 2.8% solids															
80	Demag	30	10.3	55.9	49.54	59.5	1.6	41.6	55.7	50.26	6.4	46.8	58.4	54.0	49.61	57.65	58.08
81A	On	8	9.9	54.6	49.78	58.3	2.3	72.7	60.8	55.90	2.6	44.7	27.3	32.7	20.82	16.80	12.27
81B	On	16	16.9	57.4	51.66	64.6	6.7	95.0	61.0	55.61	1.6	39.2	5.0	17.7	3.13	1.50	0.30
81C	On	24	11.6	56.1	51.45	59.4	3.5	86.0	61.6	56.21	1.8	47.5	14.0	17.2	2.49	4.35	0.72
82A	Off	8	9.6	56.6	50.57	62.8	2.3	82.2	61.1	56.03	1.8	45.4	17.8	20.0	5.83	6.62	2.20
82B	Off	16	13.0	55.9	52.14	60.3	3.6	84.9	60.4	55.84	2.1	44.4	15.1	25.8	12.15	7.06	3.73
82C	Off	24	14.8	56.7	57.65	58.9	5.6	90.8	60.4	55.87	1.9	42.3	9.2	24.7	11.33	3.98	2.01

* Circulating feed is the average of % solids of Feed.

Appendix VI. Effects of Demagnetizing – Magnetizing on Hydroseparator Performance

Feed: 30% solids (initial); 57.5% Fe; 53.79% Mag Fe
Magnetic grid: 0 layers

Test No.	Mag Coil	Time, min	Feed			Underflow					Overflow					Loss to O'flow	
			% Solids	% Fe	% Mag Fe	% Solids	Water, Gpm	% Wt.	% Fe	% Mag Fe	% Solids	Water, gpm	% Wt.	% Fe	% Mag Fe	Fe	Mag Fe
		Feed Rate: 30.5 gpm Circulating feed *: 23.6 ± 1.6% solids															
86	Demag	30	24.9	56.1	50.91	59.2	4.1	59.9	56.1	52.16	13.9	25.6	40.1	57.6	52.47	40.75	40.24
87A	On	8	25.7	57.8	52.28	59.2	5.2	83.4	60.4	56.34	5.7	24.6	16.6	40.8	33.01	11.85	10.44
87B	On	16	23.2	57.6	52.56	60.4	4.6	89.5	61.2	57.29	3.1	25.5	10.5	19.5	6.65	3.60	1.34
87C	On	24	23.7	57.7	52.38	60.3	4.6	90.2	61.6	57.92	2.9	25.5	9.8	15.9	2.27	2.73	0.42
88A	Off	8	21.7	57.7	53.15	61.1	5.1	(90)	61.0	57.93	(3.8)	22.1	(10)	15.3	1.68	2.71	0.30
88B	Off	16	21.5	57.8	53.19	62.2	3.4	88.9	62.0	58.39	2.8	24.5	11.1	15.3	1.33	2.99	0.28
88C	Off	24	24.4	57.1	52.52	62.5	4.6	91.2	61.6	58.00	2.9	24.9	8.8	15.6	2.00	2.39	0.33
		Feed Rate: 51.2 gpm Circulating feed *: 19.9 ± 1.9% solids															
89	Demag	30	22.1	56.3	51.15	64.0	2.3	34.0	54.7	51.54	15.7	42.1	66.0	56.6	49.18	66.76	64.94
90A	On	8	22.1	57.5	52.57	59.2	5.7	72.2	60.9	58.23	7.1	41.2	27.8	41.2	32.85	20.67	17.85
90B	On	16	17.7	54.6	50.16	62.0	4.4	78.9	61.0	56.90	4.4	41.9	21.1	26.2	15.37	10.30	6.74
90C	On	24	17.8	54.0	48.37	58.7	5.8	85.3	60.5	56.33	3.5	39.7	14.7	18.5	5.90	5.01	1.77
91A	Off	8	18.5	55.6	51.35	60.9	5.7	80.1	61.0	58.70	5.3	39.4	19.9	31.5	20.90	11.37	8.13
91B	Off	16	20.3	56.2	51.88	64.4	5.6	82.5	60.8	57.67	5.2	39.2	17.5	34.5	26.02	10.74	8.73
91C	Off	24	20.7	56.6	52.77	64.0	5.5	78.6	61.5	59.10	6.6	37.5	21.4	40.1	31.51	15.08	12.68

* Circulating feed is the average of % solids of Feed.

Appendix VII. Effects of Demagnetizing – Magnetizing on Hydroseparator Performance

Feed: 30% solids (initial); 59.2% Fe; 54.87% Mag Fe
Magnetic grid: 6 layers

Test No.	Mag Coil	Time, min	Feed			Underflow					Overflow					Loss to O'flow	
			% Solids	% Fe	% Mag Fe	% Solids	Water, gpm	% Wt.	% Fe	% Mag Fe	% Solids	Water, gpm	% Wt.	% Fe	% Mag Fe	Fe	Mag Fe
		Feed Rate: 33.8 gpm															
		Circulating feed *: 22.8 ± 2.9% solids															
95	Demag	30	21.0	57.0	53.08	70.4	2.9	92.6	59.5	55.85	2.0	24.6	7.4	14.0	0.42	1.85	0.06
96A	On	8	17.3	59.4	54.86	66.1	5.2	95.4	62.4	58.85	2.1	23.0	4.6	13.9	0.42	1.06	0.03
96B	On	16	23.5	60.5	56.24	59.4	5.5	93.6	61.8	57.38	2.3	24.1	6.4	14.7	0.46	1.60	0.05
96C	On	24	24.6	60.8	55.98	63.6	5.6	95.0	61.5	59.48	2.2	23.0	5.0	14.6	0.31	1.23	0.03
97A	Off	8	26.0	57.8	52.89	60.6	8.0	96.7	60.8	56.57	2.1	20.1	3.3	14.4	0.33	0.80	0.02
97B	Off	16	23.9	59.0	55.06	58.7	6.4	95.1	60.2	57.47	2.1	22.4	4.9	14.2	0.55	1.20	0.05
97C	Off	24	23.4	60.6	56.80	59.4	5.5	94.2	61.3	57.98	2.1	23.3	5.8	14.2	0.36	1.41	0.04
		Feed Rate: 50.3 gpm															
		Circulating feed *: 21.5 ± 3.5% solids															
92	Demag	30	17.6	54.2	48.51	58.6	2.9	79.2	63.2	57.04	2.8	37.5	20.8	14.7	0.70	5.76	0.32
93A	On	8	16.2	56.0	51.19	64.0	3.9	87.1	61.0	57.61	2.7	37.0	12.9	15.6	0.77	3.65	0.20
93B	On	16	26.3	59.6	54.29	61.5	3.3	94.9	62.2	58.08	2.6	29.6	5.3	15.3	0.36	1.36	0.03
93C	On	24	22.8	61.4	55.17	60.6	8.7	94.3	61.8	58.37	2.6	30.5	5.7	14.2	0.17	1.37	0.02
94A	Off	8	23.2	58.5	53.97	58.6	8.7	93.6	62.2	57.07	2.6	31.1	6.4	14.3	0.41	1.55	0.05
94B	Off	16	22.7	59.2	53.93	64.0	6.0	92.2	61.2	58.03	2.6	32.8	7.8	15.2	0.66	2.06	0.10
94C	Off	24	21.4	58.3	54.26	59.8	5.9	90.6	60.5	57.15	2.7	33.2	9.4	14.7	0.46	2.46	0.08

* Circulating feed is the average of % solids of Feed.

Appendix VIII. Effects of Demagnetizing – Magnetizing on Hydroseparator Performance

Feed: 30% solids (initial); 57.5% Fe; 53.03% Mag Fe
Magnetic grid: 4 layers

Test No.	Mag Coil	Time, min	Feed			Underflow					Overflow					Loss to O'flow	
			% Solids	% Fe	% Mag Fe	% Solids	Water, gpm	% Wt.	% Fe	% Mag Fe	% Solids	Water, gpm	% Wt.	% Fe	% Mag Fe	Fe	Mag Fe
		Feed Rate: 31.2 gpm **Circulating feed *: 21.4 ± 2.1% solids**															
98	Demag	30	17.8	55.2	51.79	63.6	4.6	95.8	57.4	55.88	1.5	23.0	4.2	14.6	1.13	1.10	0.09
99A	On	8	21.0	59.5	55.61	60.6	6.3	96.5	62.9	59.23	1.6	21.6	3.5	15.0	0.99	0.86	0.06
99B	On	16	22.8	60.5	57.21	59.3	6.0	95.7	61.1	59.04	1.7	22.9	4.3	16.4	1.00	1.19	0.08
99C	On	24	22.2	59.2	58.01	60.0	4.9	94.5	61.0	56.77	1.7	24.6	5.5	15.3	1.04	1.44	0.11
100A	Off	8	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
100B	Off	16	(27.2)	58.9	56.18	(56.1)	2.5	(90)	60.2	58.80	(1.4)	25.6	(10)	15.2	0.70	2.73	0.13
100C	Off	24	23.0	61.0	55.17	61.4	3.5	93.6	60.9	59.77	1.6	24.0	6.4	15.1	0.59	1.67	0.07
		Feed Rate: 50.0gpm **Circulating feed *: 19.6 ± 2.1% solids**															
101	Demag	30	15.2	56.1	52.12	62.3	3.8	89.1	59.9	57.04	1.9	39.3	10.9	15.8	1.56	3.13	0.33
102A	On	8	20.8	58.2	54.15	62.1	8.5	95.7	59.9	59.41	1.8	34.0	4.3	14.6	0.74	1.08	0.06
102B	On	16	21.4	58.4	56.46	60.5	6.6	93.5	62.4	57.83	1.9	35.9	6.5	14.5	0.48	1.59	0.06
102C	On	24	20.2	59.0	55.13	55.8	7.6	93.1	62.9	58.42	1.9	35.8	6.9	15.1	0.54	1.75	0.07
103A	Off	8	20.1	58.7	55.74	59.7	6.5	92.9	61.8	60.52	1.9	37.0	7.1	14.7	0.64	1.79	0.08
103B	Off	16	20.3	58.9	54.73	58.3	7.0	93.4	61.5	59.06	1.9	36.2	6.6	15.2	0.89	1.72	0.11
103C	Off	24	18.9	58.0	54.97	58.6	5.3	90.9	61.0	58.99	1.9	38.0	9.1	14.6	0.59	2.34	0.10

* Circulating feed is the average of % solids of Feed.

Appendix IX. Effects of Demagnetizing – Magnetizing on Hydroseparator Performance

Feed: 30% solids (initial); 58.4% Fe; 56.6% Mag Fe
Magnetic grid: 2 layers

Test No.	Mag Coil	Time, min	Feed			Underflow					Overflow					Loss to O'flow	
			% Solids	% Fe	% Mag Fe	% Solids	Water, gpm	% Wt.	% Fe	% Mag Fe	% Solids	Water, gpm	% Wt.	% Fe	% Mag Fe	Fe	Mag Fe
		Feed Rate: 31.9 gpm Circulating feed *: 18.5 ± 3.7% solids															
107	Demag	30	12.8	56.3	49.78	61.2	2.4	90.6	59.6	54.67	1.5	26.4	9.4	16.0	1.93	2.71	0.36
108A	On	8	14.4	57.1	51.81	67.3	2.3	92.3	61.2	55.38	1.5	25.7	7.7	15.6	1.66	2.08	0.25
108B	On	16	18.9	58.9	53.73	63.1	6.1	96.8	61.7	56.75	1.5	21.9	3.2	15.4	1.00	0.82	0.06
108C	On	24	21.3	59.5	53.64	60.9	5.4	95.8	62.3	57.43	1.6	22.7	4.2	16.1	0.60	1.12	0.05
109A	Off	8	23.5	59.4	54.23	57.5	5.7	95.5	61.2	57.07	1.6	22.7	4.5	15.6	0.78	1.19	0.06
109B	Off	16	19.4	59.4	53.31	59.4	4.2	93.9	61.4	55.87	1.6	24.2	6.1	14.9	0.58	1.55	0.07
109C	Off	24	19.1	59.2	53.14	61.3	4.3	94.6	61.2	56.76	1.6	24.1	5.4	15.4	0.46	1.42	0.05
		Feed Rate: 51.0 gpm Circulating feed *: 17.5 ± 1.1% solids															
104	Demag	30	17.1	56.1	51.05	64.0	5.6	93.0	60.7	56.89	2.0	35.9	7.0	16.4	2.12	1.99	0.28
105A	On	8	18.7	57.3	54.25	59.7	6.1	92.1	61.0	56.78	2.1	36.7	7.9	14.8	0.91	2.04	0.14
105B	On	16	18.8	57.4	53.68	58.9	5.7	91.3	61.0	57.77	2.1	36.1	8.7	14.7	0.66	2.24	0.11
105C	On	24	17.7	57.3	52.50	59.2	6.2	92.0	61.5	57.92	2.1	36.8	8.0	14.6	0.66	2.02	0.10
106A	Off	8	17.6	57.4	52.88	61.7	5.0	91.3	61.1	57.40	2.1	35.8	8.7	15.8	0.92	2.40	0.15
106B	Off	16	16.1	57.2	51.79	60.5	5.0	90.0	62.0	56.75	2.0	37.7	10.0	15.9	0.69	2.77	0.13
106C	Off	24	16.2	58.1	51.84	57.9	5.5	91.0	62.0	56.89	2.0	37.7	9.0	15.1	0.53	2.35	0.09

* Circulating feed is the average of % solids of Feed.

Appendix X. Effects of Demagnetizing – Magnetizing on Hydroseparator Performance

Feed: 30% solids (initial); 58.8% Fe; 53.9% Mag Fe
Magnetic grid: 1 layer

Test No.	Mag Coil	Time, min	Feed			Underflow					Overflow					Loss to O'flow	
			% Solids	% Fe	% Mag Fe	% Solids	Water, gpm	% Wt.	% Fe	% Mag Fe	% Solids	Water, gpm	% Wt.	% Fe	% Mag Fe	Fe	Mag Fe
		Feed Rate: 30.8 gpm Circulating feed *: 18.8 ± 4.3% solids															
110	Demag	30	13.7	56.3	50.01	63.0	1.6	86.5	60.8	55.01	1.5	27.6	13.5	17.6	3.41	4.32	0.96
111A	On	8	13.6	56.7	50.88	69.1	2.0	91.6	61.3	56.54	1.5	26.1	8.4	16.2	1.96	2.37	0.32
111B	On	16	18.7	58.9	52.96	62.8	6.4	97.0	61.8	56.82	1.5	22.2	3.0	15.9	0.85	0.79	0.05
111C	On	24	26.2	59.6	55.05	60.0	7.5	97.3	61.2	57.15	1.5	20.9	2.7	16.2	0.81	0.73	0.04
112A	Off	8	20.4	59.1	54.25	61.9	2.1	93.5	60.8	56.10	1.6	27.0	(6.5)	15.4	0.81	1.73	0.10
112B	Off	16	19.3	58.8	53.57	59.5	3.9	95.5	60.7	56.75	1.5	22.6	4.5	15.4	0.85	1.18	0.07
112C	Off	24	19.9	58.7	53.21	61.6	5.2	94.9	61.0	56.06	1.5	24.5	5.1	16.1	0.67	1.40	0.06
		Feed Rate: 53.4 gpm Circulating feed *: 14.8 ± 2.1% solids															
113	Demag	30	11.4	55.4	48.85	59.9	3.7	85.3	59.9	55.82	2.2	42.1	14.7	26.0	14.11	6.96	4.17
114A	On	8	17.3	57.2	52.33	60.8	7.7	94.7	62.3	57.98	1.7	38.6	5.3	15.4	1.60	1.36	0.15
114B	On	16	14.6	56.7	52.20	62.9	5.0	(90.5)	61.2	57.80	2.0	43.1	(9.5)	14.9	1.13	2.49	0.20
114C	On	24	16.5	58.2	53.24	57.9	7.0	93.2	59.6	57.58	1.8	39.1	6.8	15.4	0.78	1.85	0.10
115A	Off	8	16.4	56.6	52.71	58.4	6.2	92.2	61.5	56.94	1.8	40.8	7.8	15.3	1.01	2.06	0.15
115B	Off	16	13.8	57.0	51.22	61.9	3.7	88.1	61.0	56.33	1.9	42.1	11.9	15.8	1.21	3.38	0.29
115C	Off	24	13.7	56.5	52.18	65.4	3.5	89.6	61.1	56.81	1.8	42.2	10.4	15.5	0.89	2.86	0.18

* Circulating feed is the average of % solids of Feed.

Appendix XI. Effect of Feed Rates on Hydroseparator Performance

Test No.	Feed, gpm	Feed			Underflow					Overflow				O'flow Rate		Loss to O'flow	
		% Solids	% Fe	% Mag Fe	% Solids	Water, gpm	% Wt.	% Fe	% Mag Fe	% Solids	% Wt.	% Fe	% Mag Fe	gpm	mm/sec	Fe	Mag Fe
		Magnetic grid: 6 layers Feed: 30% solids (initial); 61.5% Fe, 56.78% Mag Fe Demagnetized															
116	43.4	15.3	57.0	51.71	59.9	3.8	91.7	61.4	57.11	1.5	8.3	17.1	1.61	33.7	3.2	2.46	0.25
117	60.7	14.8	59.0	54.00	60.3	5.0	90.7	61.9	57.84	1.7	9.3	17.2	1.89	44.1	4.2	2.77	0.33
118	70.1	14.4	57.5	52.37	64.2	5.1	89.7	61.8	59.04	1.9	10.3	17.1	1.82	53.8	5.2	3.08	0.35
119	80.4	13.2	56.0	50.41	63.6	5.1	86.0	62.9	58.11	2.0	14.0	17.4	2.05	60.2	5.8	4.31	0.57
		Magnetic grid: 4 layers Feed: 30% solids (initial); 60.1% Fe, 54.23% Mag Fe Demagnetized															
120	41.2	16.2	56.6	52.30	61.8	3.7	92.6	60.1	56.63	1.4	7.4	16.7	2.06	33.0	3.2	2.17	0.29
121	62.2	16.7	56.4	53.71	60.3	6.4	92.0	60.4	57.56	1.8	8.0	17.7	3.09	45.9	4.4	2.48	0.46
122	70.4	14.8	56.1	52.00	61.0	5.3	88.1	60.9	56.96	2.0	11.9	18.4	3.75	56.3	5.4	3.92	0.88
		Magnetized (50A)															
123	70.4	16.4	57.4	52.86	57.0	8.1	91.8	61.1	58.31	1.8	8.2	14.8	0.44	53.2	5.1	2.12	0.07
124	79.7	14.5	57.0	53.60	64.8	5.8	90.4	61.9	58.20	1.9	9.6	14.9	0.85	59.9	5.8	2.50	0.15

Appendix XII. Effect of Magnetizing Current on Hydroseparator Performance

Test No.	Mag Coil A	Feed			Underflow					Overflow					Loss to O'flow	
		% Solids	% Fe	% Mag Fe	% Solids	Water, gpm	% Wt.	% Fe	% Mag Fe	% Solids	Water, gpm	% Wt.	% Fe	% Mag Fe	Fe	Mag Fe
		Magnetic grid: 4 layers Feed: 30% solds (initial); 59.5% Fe, 54.97% Mag Fe Feed rate: 70 gpm														
125	Demag	13.6	56.3	51.27	61.5	5.8	87.1	63.3	59.49	2.4	56.8	12.9	19.5	4.78	4.36	1.18
126	10	15.7	58.0	52.79	61.6	6.7	90.1	63.7	60.23	2.1	55.3	9.9	16.5	1.26	2.77	0.23
127	20	15.7	58.2	53.99	61.7	5.9	89.2	62.9	59.43	2.1	54.6	10.8	16.1	0.85	3.01	0.17
128	30	14.2	57.4	53.01	61.7	5.6	88.9	62.0	59.28	2.0	56.9	11.1	15.8	0.94	3.08	0.20
129	40	14.3	58.0	52.89	61.7	5.6	89.1	61.3	57.77	1.9	55.9	10.9	14.4	0.81	2.79	0.17
130	50	14.6	56.7	52.60	59.4	4.3	83.5	61.9	59.82	2.0	59.5	16.5	15.5	0.81	4.62	0.26
		Feed rate: 50 gpm														
131	Demag	13.8	56.7	51.66	62.8	3.8	91.5	59.6	56.40	1.5	38.9	8.5	17.3	2.68	2.63	0.44
132	50	19.7	60.9	56.79	55.5	6.7	94.0	61.6	58.81	1.5	34.4	6.0	15.2	0.50	1.55	0.05
		Magnetic grid: 4 layers Feed: 30% solids (initial); 60.0% Fe, 55.94% Mag Fe Feed rate: 51.5 gpm														
133	Demag	13.8	57.3	52.44	64.4	2.9	88.8	62.8	59.22	1.7	38.4	11.2	16.1	1.72	3.13	0.36
134	10	17.7	58.2	54.45	73.3	3.5	94.0	61.6	59.56	1.6	36.6	6.0	15.2	0.96	1.55	0.10
135	20	17.4	57.6	55.23	64.5	4.5	92.9	61.9	60.17	1.6	37.8	7.1	15.1	0.92	1.83	0.12
136	30	19.4	59.9	55.39	62.5	6.0	94.6	62.3	58.39	1.6	35.7	5.4	14.8	0.42	1.34	0.04
137	40	19.2	59.5	56.71	67.5	4.7	94.3	62.4	59.75	1.5	35.9	5.7	15.5	0.63	1.48	0.06
138	50	18.2	58.6	55.23	62.0	5.1	93.5	61.7	61.41	1.5	36.8	6.5	15.0	0.58	1.66	0.07